MODIFICATION OF THE FJORTOFT GRAPHICAL PROGNOSIS METHOD

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GRAPHICAL PROGNOSIS METHOD

by

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ABSTRACT

This paper presents a relatively simple method for producing a 24-hour prognostic 500-mb chart by graphical means. It modifies the Fjortoft graphical method by incorporating a technique to include the intensification and weakening of systems. That is, it uses factors which allow intensification of poleward-moving cyclones and weakening of equatorward-moving cyclones and the converse for anticyclones.

The theoretical development of the so-called "geostrophic model" used, the research procedure, and a number of illustrative charts are all discussed and a table of chart verification scores is presented to assist in the reader's evaluation of the method.

It is concluded that this method does provide a simple prognostic procedure which includes some intensity change for systems. The results showed an average 24.9 per cent improvement over persistence for the charts analyzed using a height-gradient verification scheme.

Appendix I outlines the specific procedure for utilizing the method on a practical basis and is included as such for the convenience of potential users.

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[illegible] [illegible]

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[illegible]

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TABLE OF SYMBOLS AND ABBREVIATIONS

ζ	Vertical component of the relative vorticity; referred to as "relative vorticity"
ζ_a	Vertical component of the absolute vorticity; referred to as "absolute vorticity"
ζ_g	Geostrophic relative vorticity
$\mathbb{V}$	Horizontal wind velocity
$\mathbb{V}_g$	Geostrophic horizontal wind velocity
$\overline{\mathbb{V}}_g$	Space-mean geostrophic horizontal wind velocity
$\overline{v}_g$	Meridional component of $\overline{\mathbb{V}}_g$
t	Time
ω	Vertical component of velocity in (x,y,p,t) coordinate system
g	Gravitational force per unit mass
d	Space-mean grid distance
m	Map-scale constant
ϕ	Latitude
p	Pressure
f	Coriolis parameter,
Ω	Angular velocity of the earth
a	Mean radius of the earth
Z	Contour height
$\bar{Z}$	Space-mean contour height
$(\bar{Z}-Z)$	Graphically obtained quantity proportional to relative vorticity
mb	Millibars
$\mathbb{K}$	Vertical unit vector

1. Introduction.

The Fjortoft graphical method of prognosis of the 500-mb constant pressure surface utilizing the barotropic vorticity equation is based on the advection of relative vorticity by the space-mean geostrophic wind together with the advection of earth's vorticity by a "J" term [4]. This "J" term is a function of latitude only, for a given map projection and grid distance [5, p. 397]. In final form, the method combines these two terms to produce an advection of absolute vorticity from which can be recovered the desired height-contour prognosis.

The Fjortoft method, in slightly simplified form, has been utilized by a group of 25 students in meteorological laboratory forecasting exercises together with height-change methods, control line techniques, and purely subjective approaches. The Fjortoft method produced, for most students, the best results of the methods used as verified by the same height-gradient grid system used later in this paper.

Because of the assumption of barotropy, the Fjortoft method does not forecast intensity changes, in contrast to the method here proposed which will provide for some intensity changes.

2. Theoretical Development of the "Geostrophic Model."

The isobaric (x,y,p,t) coordinate system is used throughout the following development and symbols are as defined in the Table of Symbols and Abbreviations, page 9 . The basic model has been developed by W. D. Duthie [3], and only an outline and necessary amplification of his development are given here.

With relative vorticity defined by

$$\zeta = \mathbb{K} \cdot \nabla \times \mathbb{V} \tag{1}$$

and the geostrophic wind by

$$\mathbb{V}_g = \frac{g}{f} \mathbb{K} \times \nabla Z \tag{2}$$

it is shown that the geostrophic vorticity is given by

$$\zeta_g = \frac{g}{f}\left[\nabla^2 Z - \nabla Z \cdot \nabla \ln f\right] . \tag{3}$$

Duthie then shows that the divergence, using the geostrophic wind, can be written

$$\nabla \cdot \mathbb{V}_g = -\mathbb{V}_g \cdot \nabla \ln f . \tag{4}$$

For frictionless flow the isobaric vorticity equation is

$$\frac{d}{dt}(\zeta_a) = -\zeta_a \nabla \cdot \mathbb{V} + T \qquad \text{(Twisting term)} \tag{5}$$

or, if it is assumed that $T \doteq \omega \frac{\partial \zeta}{\partial p}$, then

$$\frac{D}{Dt}(\ln \zeta_a) \doteq -\nabla \cdot \mathbb{V} . \tag{6}$$

Now, using $\mathbb{V} \doteq \mathbb{V}_g$ and equation (4), then (6) can be written

$$\frac{D}{Dt}\left(\frac{\zeta_g}{f}\right) = 0 \tag{7}$$

or

$$\frac{D}{Dt}\left(\zeta_g\right) = \frac{\zeta_g}{f}\,\frac{Df}{Dt} \quad , \tag{8}$$

which shows that a model based on (7) or (8) will give poleward-moving parcels an increase in magnitude of any relative vorticity they might have and a decrease for equatorward movement.

Equation (8), of course, can be expanded to

$$\frac{\partial}{\partial t}(\zeta_g) = -\mathbb{V}_g \cdot \nabla \zeta_g + \zeta_g/_f \; \mathbb{V}_g \cdot \nabla f \; , \tag{9}$$

which might be considered the basic equation of the so-called "geostrophic model." This is in contrast to Fjortoft's simplest model [5, p. 397], which neglects the last term in (9). By retaining this term in the present model a quasi-divergence is retained which will subsequently be applied and manipulated in an empirical sense.

Equation (3) is now used in its normal approximating form

$$\zeta_g \doteq g/_f \; \nabla^2 Z \tag{10}$$

and put in finite difference form

$$\zeta_g \doteq \frac{4gm^2}{fd^2}\left(\overline{Z} - Z\right) . \tag{11}$$

When (11) is used in (9) and m taken to be constant, the result is

$$\frac{\partial}{\partial t}(\overline{Z}-Z) = -\overline{\mathbb{V}}_g \cdot \nabla(\overline{Z}-Z) + \frac{2(\overline{Z}-Z)}{f}\,\mathbb{V}_g \cdot \nabla f \quad , \tag{12}$$

where $\overline{\mathbb{V}_g}$ is substituted for $\mathbb{V}_g$ in the advection of ∇f as an approximation. This, then, is the basic working equation of the "geostrophic model," giving a prognostic equation for the quantity $(\overline{Z}-Z)$ which is proportional to relative vorticity by (11). From a prognosis of $(\overline{Z}-Z)$ can be recovered a corresponding height prognosis either by a simple graphical subtraction, if the space-mean field is taken to be constant for the period, or by a more complicated relaxation procedure if this assumption is not made [5, p. 398].

For practical use, the last term of (12) can be written

$$\frac{2(\overline{Z}-Z)}{f}\,\overline{\mathbb{V}_g}\cdot\nabla f = \overline{v_g}\,\frac{1}{A(\phi)}\,(\overline{Z}-Z) \qquad (13)$$

where $\quad 1/A(\phi) = \dfrac{2\cot\phi}{a}$.

$\overline{v_g}$ is positive for poleward flow and negative for equatorward flow. The sign of the term given by (13) is thus determined by the signs of $\overline{v_g}$ and $(\overline{Z}-Z)$. $A(\phi)$ varies as a function of latitude as shown in Table 1 for 24-hour displacements (for $\overline{v_g}$ in knots).

Table 1

Variation of $A(\phi)$ with Latitude

ϕ	20	25	30	35	40	45	50	55	60	65	70	75
$A(\phi)$	26	33	41	50	59	72	85	102	124	153	196	248

For practical use, a table, such as the one used by the authors and shown as Table 3, can be developed for the last term of (12), referred to hereafter as the correction term.

The purpose of the research on this model then is to develop a routine prognostic system with the following general steps:

a. from a current contour chart produce a space-mean chart and a $(\overline{Z}-Z)$ field;

b. advect this $(\overline{Z}-Z)$ field using $\overline{V_g}$ or some modification thereof;

c. apply the correction term to give intensity changes in the $(\overline{Z}-Z)$ field and some resulting modification of its pattern;

and d. from the advected and modified $(\overline{Z}-Z)$ field recover a prognostic height field.

3. Research Procedure.

As research data for this paper several series of 500-mb charts were selected from the U. S. Naval Postgraduate School meteorological library files. These charts cover the area from approximately 40E to 145W and 20N to 90N on polar stereographic projection with a scale of 1:15,000,000. The charts selected covered a wide range of situations and included dates in January 1962, January 1964, and February 1964.

The preliminary step was to prepare standard space-mean charts with 60-meter intervals by graphical means utilizing a grid distance of five degrees at 25N [1, p. 8]. The $(\overline{Z}-Z)$ field was then obtained by graphical subtraction of the 500-mb chart from the space-mean chart. For convenience in later steps the $(\overline{Z}-Z)$ field was superimposed on the space-mean chart.

The initial approach to advection of $(\overline{Z}-Z)$, which is proportional to relative vorticity, was to use the measured space-mean geostrophic wind, $\overline{\mathbb{V}_g}$, at the initial pattern location and apply this speed over a 24-hour period along the mean contour lines. In general, each intersection of the $(\overline{Z}-Z)$ field with mean contours was treated in this manner and an advected $(\overline{Z}-Z)$ field was thus obtained. The advected patterns were then compared graphically with actual positions on verifying charts with a resulting error field. The correction term was then applied to the advected field and another error field obtained for comparative purposes.

After using this technique on many charts it was determined that serious errors in advection were occurring mainly due to the measured values of space-mean geostrophic wind in regions of troughs and ridges. Other attempts were made using a wind measurement at varying locations downstream of the point being advected, all with little success.

For practical use a quick, qualitative correction to the measured geostrophic wind was deemed necessary in view of the foregoing results. Therefore a gradient-wind approximation was utilized based on the well-known principle that gradient wind is less than geostrophic in troughs (cyclonic curvature) and greater than geostrophic with anti-cyclonic curvature. To keep the determination of wind speed quite simple in this modification the rough fractions and multiples illustrated in fig. 1 were used [2, pp. 2-9 to 2-11]. The particular factor used was that one pertaining to the <u>initial</u> location of the advection point and rough interpolation was used. For example, a factor of 3/4 $\overline{V_g}$ would be used for an advection point originating midway between a trough and an adjacent inflection point.

This technique worked quite well and was the basic change resulting in the so-called revision II(REV II) method.

Two special situations were encountered which required a subjective modification of the revision II (and later, the revision III) advection techniques based on situations of dynamic imbalance which are identifiable on the 500-mb chart. The first of these arises when a definite cut-off low exists with a strong zonal flow indicated poleward of the center both on the 500-mb and the space-mean charts. Under these conditions a negative ($\overline{Z}$-Z) center in the ridge west of the low was found to advect strictly along the strong flow north of the low, rather than to have it split with one part moving equatorward. This situation is illustrated in fig. 2(a) and in the discussion of 051200Z February 1964 and its associated charts. The error field was considerably reduced by this application.

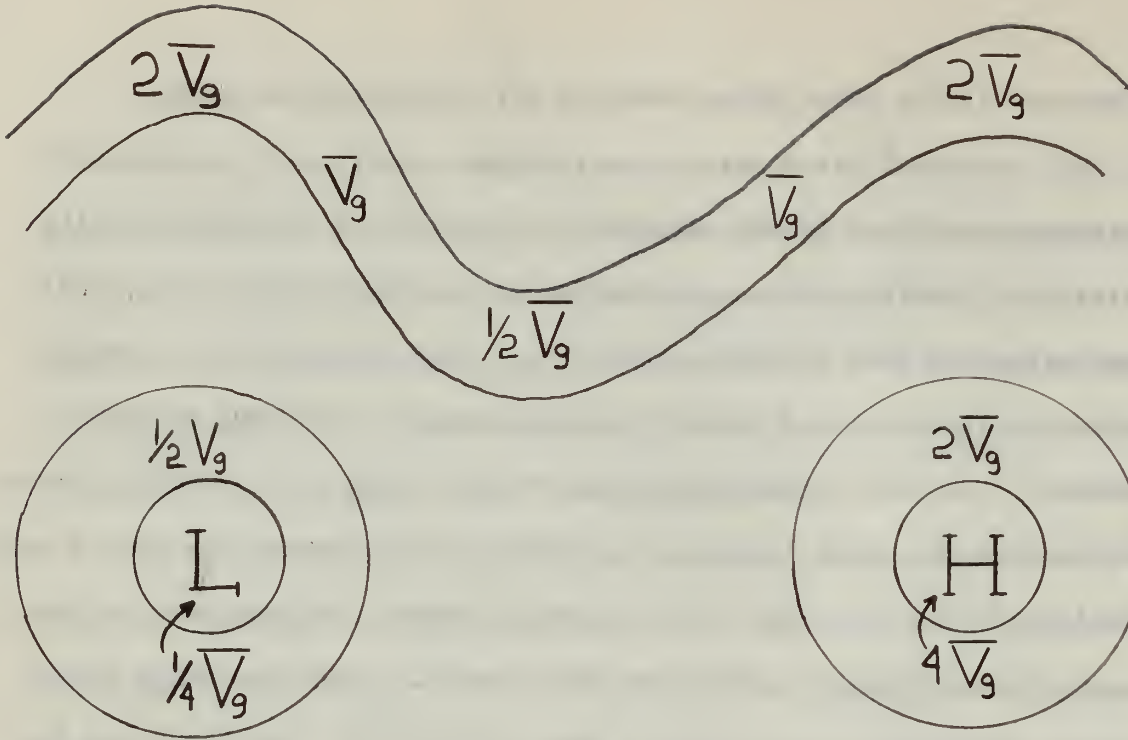

Fig. 1

Modification of the space-mean geostrophic wind, $\overline{V}_g$, to approximate the gradient wind

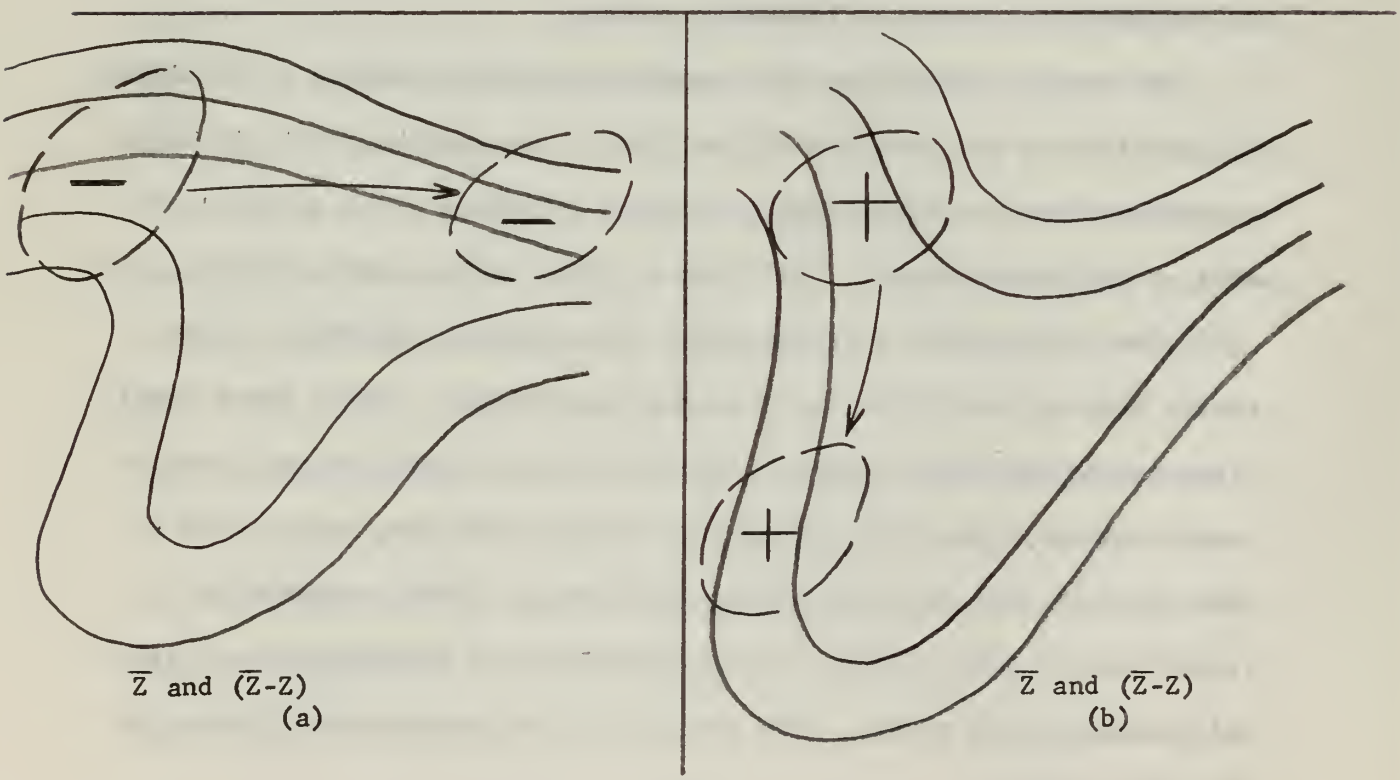

Fig. 2

Modification of the advection of $(\overline{Z}-Z)$ along $\overline{Z}$ in special situations

The second special situation involves strong equatorward flow west of a trough such that a dynamic imbalance situation as illustrated in fig. 2(b) is indicated. Here the modification applies to positive $(\overline{Z}-Z)$ centers located in or near this major equatorward flow. These should be advected with the equatorward flow even though they do not lie entirely or even mostly in this flow. This is illustrated in the 061200Z February 1964 discussion and again a significant improvement was obtained.

Revision II methods were then used for advection and, together with the correction term, resulted in revision II prognoses of $(\overline{Z}-Z)$ which are illustrated and discussed in section 4.

So far, in order to keep the technique simple, only an instantaneously measured space-mean geostrophic wind has been used for advection and this obviously will introduce a great deal of error when all the possible parcel trajectories are considered over a 24-hour period. Undoubtedly, numerous sophisticated advection devices could be employed to improve this situation, perhaps at the expense of considerable time. As a step in this direction a further rather simple modification was used, called revision III (REV III). This revision applies mainly where the space-mean contours converge, diverge, or curve markedly in the advected distance, and consists simply in carrying out both the advection and correction steps in two twelve-hour steps on the same space-mean chart, using the revision II gradient wind approximation in each step. This can be done with only a slight increase in the time required and need not be done at every advection point. The further reduction in error brought about by this improvement can be appreciated by a study of error fields and resulting prognoses as shown in section 4.

4. Discussion of Illustrative Charts.

This section discusses a number of charts used in the research which represent typical as well as good and poor results. This is done by including and commenting on initial charts, revisions and error fields experimented with, resulting products, and verifying charts. All work was done using H. O. 6833, a polar stereographic projection covering North America and much of the adjacent ocean area. The scale of the basic chart is 1:15,000,000, with subsequent photo-reduction to appropriate page size.

For the discussion some $(\overline{Z}-Z)$ centers have been labeled with capital letters to aid in identification of features discussed. This is in addition to the plus and minus labels used in all centers and in areas enclosed by zero lines where needed for clarity.

The advantage of superimposing space-mean contours on the error fields and the prognostic $(\overline{Z}-Z)$ fields for reference purposes was weighed with the conclusion being that the detail lost in photo-reduction would nullify the advantage. It should be pointed out also that error fields were obtained by graphical subtraction of the verifying $(\overline{Z}-Z)$ from the prognostic $(\overline{Z}-Z)$ field; hence the errors are the amounts by which the <u>prognosis</u> of $(\overline{Z}-Z)$ verifies above or below the <u>verifying</u> $(\overline{Z}-Z)$ field for plus and minus sign respectively.

In the following discussion it should be recalled that revision II is the technique of approximating the gradient wind for advective purposes using multiples of space-mean geostrophic wind as shown in fig. 1. Revision II, modified, is the same principle coupled with the subjective modification for a cut-off low as illustrated in fig. 2. Revision III involves the refinement of using two 12-hour time steps, on the same space-mean chart, in carrying out the advection and correction processes. Revision III can also be subjectively modified in the cut-off low situation.

As a means of quantitatively evaluating and comparing the methods, a height-gradient verification scheme used at the U. S. Naval Postgraduate School was utilized. While this method does not completely evaluate all facets of a prognosis, such as locations of centers and specific height contours it does assign a meaningful score.

This method employs a grid of 55 stations or points over an area between 25N and 65N and 60W and 150W. Height gradients between grid points in north-south and east-west directions are obtained from prognostic and verifying charts. These values are compared for corresponding intervals and a total gradient error is obtained. This total gradient error, expressed as a fraction of the total gradient of the verifying chart, is called the verification score. Thus, the lower the score, the better is the prognosis as determined by this method.

Finally, it must be mentioned that throughout this project, when the 500-mb prognosis was recovered from the prognostic ($\overline{Z}$-Z) chart, the space-mean field was assumed to remain constant through the 24-hour period. Thus a simple graphical subtraction was all that was necessary to recover a 500-mb prognosis. If this assumption is not made, a relaxation process is necessary to recover the height prognosis [5, p. 398], and this would be expected to yield somewhat better results if the time is available.

7 - 8 January 1962

This set of charts is based on a typical 500-mb level contour pattern featuring a deep trough over the United States, the Pacific subtropical high just off the West Coast, and a cyclone in the Aleutians.

Figs. 3 through 13 illustrate the situation and research steps starting with the 070000Z JAN 1962 500-mb chart and leading, finally, to the 080000Z JAN 1962 500-mb chart for verification.

Fig. 4 shows the space mean and $(\overline{Z}-Z)$ fields obtained from the 070000Z 500-mb chart. This space-mean was assumed to be constant for the ensuing 24-hour period, as was done throughout this research. Note how the space-mean flow has "smoothed out" relative to the basic 500-mb flow and that closed centers, especially cyclones in troughs, tend to vanish in the space-mean process. This, of course, is to be expected and was typical throughout. Note also how the positive $(\overline{Z}-Z)$ centers closely correspond with locations of closed lows or troughs and the negative centers with highs or ridges. Fig. 5 is the space-mean and $(\overline{Z}-Z)$ for 080000Z JAN 1962 and shows the characteristics just mentioned when compared to its 500-mb chart, fig. 13. Time continuity of $(\overline{Z}-Z)$ patterns can be seen between figs. 4 and 5; for example, see the center labeled A.

Charts showing initial attempts at advection and application of the correction term, in which instantaneous space-mean geostrophic winds and other attempts were utilized, are not included except for the error field for revision I, fig. 10. This will be seen to have considerably larger areas of error than in succeeding techniques.

The next step in the research is illustrated in fig. 6, the revision II $(\overline{Z}-Z)$ prognosis, in which the rough gradient wind approximation was used (see fig. 1). The results in this case were much more satisfactory, especially with respect to the location of $(\overline{Z}-Z)$ centers.

This is seen in fig. 9 by a decrease in the area of the error fields, particularly in the Aleutian area. Fig. 11 next shows further reduction in the size and number of the error centers when the correction term is applied to the advected field.

Fig. 7 shows the result of using the revision III technique, in which advection and correction is done in two 12-hour steps. This procedure was of particular importance in area A. With revision II, fig. 6, the plus-12 center resulting from area A in fig. 4 was placed too far to the northeast and would have resulted in a poor product for the 080000Z prognosis. The result utilizing revision III, shown in fig. 7, is much more satisfactory. Based on subsequent experience, it is also concluded that the intermediate value plus-9 lines, generated by the correction term, should have been drawn as this would have deepened the 5310-meter low on the prognostic 500-mb chart at area A. The positive center which moved into the previous A position in the trough was, however, weakened with the revision III technique, contrary to the verifying situation. But the net result was considerably favorable for revision III. The reduction in error areas for this method is shown in fig. 12, being especially notable for area A.

The resulting 500-mb prognosis for revision III techniques verified at .368 compared to .423 for a simple Fjortoft technique [5, pp. 397-398] and .563 for persistence.

9 - 10 January 1962

This series illustrates another quite typical situation very similar to the previous one. Figs. 14 through 20 are applicable.

By comparing fig. 16, the revision II ($\overline{Z}$-Z) prognosis, and fig. 17, revision III, with the verifying chart, fig. 18, the improvement gained by a two-step advection can be seen. This is particularly notable for areas B and C. Area A could only be advected to the position shown, whereas some cross-contour displacement to the northeast would have been required for better verification.

The resulting 500-mb prognosis from revision III, fig. 19, was verified against fig. 20 and a verification score of .376 was obtained as against .463 for persistence. The general correspondence in pattern was good and, in particular, the 5160-meter center over the Great Lakes area on the prognostic 500-mb chart corresponded very well with the 5160-meter deep trough on the verifying chart. This system had weakened from a 5100-meter closed center, shown in fig. 14. This weakening also shows up in the $(\overline{Z}-Z)$ field as seen by comparing figs. 15 and 17.

4 - 5 February 1964

The special situation illustrated in this series is that of treating a cut-off low, which resulted in some suggested subjective modifications of the advective process. The cut-off system and its associated ridge to the west may be seen in fig. 21, the 041200Z analysis. These are the dominant features of this chart. These same features still show well on the space mean, fig. 22, and the discussion will deal with this situation in particular.

Area G in figs. 22, 23, and 24 illustrates the recommended modification due to a negative relative vorticity center being located in a strong, sharply-curved ridge upstream of a well-developed cut-off low. With strict advection as in fig. 23, utilizing the revision II prognosis, the minus-6 $(\overline{Z}-Z)$ center indicated as G split into two parts, labeled G and G'. The G' area would tend to weaken the trough which is erroneous as seen by comparing figs. 23 and 25 even after the correction term, here a weakening effect, is applied. It was then concluded that the original area G should have been advected only with the relatively strong flow poleward of the cut-off low. When this was done an improvement was gained as shown by comparison of the resulting prognosis, fig. 24, with fig. 23 and with the verifying $(\overline{Z}\text{-}Z)$ chart in fig. 25.

Area H, the positive $(\overline{Z}\text{-}Z)$ center associated with the cut-off low, did not increase its vorticity, even with the correction term, since there was essentially no net poleward movement for the pattern and also due to the rather weak gradient around the low. In actuality, the verifying $(\overline{Z}\text{-}Z)$ chart did show an increase in vorticity in this area as indicated by the plus-18 $(\overline{Z}\text{-}Z)$ value in fig. 25. This was coincident with a deepening of the cut-off low as may be seen in fig. 28. However, the prognostic location of the cut-off low was quite accurate.

The resulting 500-mb chart, fig. 26, verified at .740 with the modified revision II technique, compared to .818 for persistence.

One reason for the poor score on this chart was indicated by large verification errors in the western United States. These errors were attributed to an inaccurate analysis in the Pacific and a corresponding poor $(\overline{Z}\text{-}Z)$ pattern being advected onto the continent.

5 - 6 February 1964

This set of charts further illustrates the cut-off low situation and figs. 25 and 27 through 32 apply.

In fig. 27 very strong meridional flow can be observed to the west of the cut-off low downstream from the ridge. Superimposed on the strong flow there is a positive $(\overline{Z}\text{-}Z)$ area, labeled I and shown in fig. 25. It must be noted that the basic 500-mb chart would have to be utilized to detect this characteristic as the gradient is reduced considerably in the process of producing the space mean.

With advection by revision II, area I moved to the position shown in fig. 28. This position was in error as noted by comparison with the verifying chart, fig. 30.

As a trial modification the positive center I was then moved equatorward along the strong flow. Fig. 29 shows the result. Application of the correction term decreased the size of the area too much but the overall pattern was quite satisfactory.

Area H, however, maintained a plus-18 value when advected and corrected, due to the sign of the correction term for poleward movement. The weakening exhibited for this area by the actual chart, fig. 30, could not be obtained or explained.

Fig. 31 shows excellent correspondence to the analyzed 500-mb for 061200Z, fig. 32. Some ridging even shows up poleward of the cut-off low and other features are in close agreement. This revision II, modified, prognosis verified with a .262 score as compared to the .940 score with the simplified Fjortoft method[5, pp. 397-398] and .818 for persistence.

Other Charts

The concepts illustrated in the preceeding examples were verified by other charts not included herein. The correction term was observed to weaken and intensify $(\overline{Z}-Z)$ centers properly, in general, although its exact magnitude and variation could not be verified due to the interrelationship of the advective term and the correction term. In the large majority of cases the correction was verified as being in the proper "direction." In this regard, it might be pointed out that considerable investigation was conducted using error fields for pure advection and their relationship to the space-mean and basic 500-mb patterns in an attempt to pinpoint the exact nature of the correction term. No consistent correlation was evident and, as mentioned just above, this is attributed to the seemingly complicated connection between the two terms of the prognostic equation together with the necessarily inexact advection methods.

Vorticity areas in the Pacific area, as indicated by $(\overline{Z}-Z)$ centers, usually were difficult to deal with as they were necessarily advected onto the continent, but more often than not turned out to be fictitious centers due to a basically poor 500-mb analysis in the sparse data areas. In no case, however, were these areas subjectively dropped and they undoubtedly contributed to somewhat poorer products, even though they often disappeared on reaching areas of good data. The basic problem is not unique to this research effort, of course!

In some cases an intermediate analysis with 30-meter intervals was found to be of considerable help in obtaining a good prognosis. This can readily be obtained in rough fashion in local areas just by drawing intermediate lines by interpolation, both on the space mean and the $(\overline{Z}-Z)$ or with greater accuracy by drawing every space-mean contour when the north-south and east-west charts are added in the space-mean procedure.

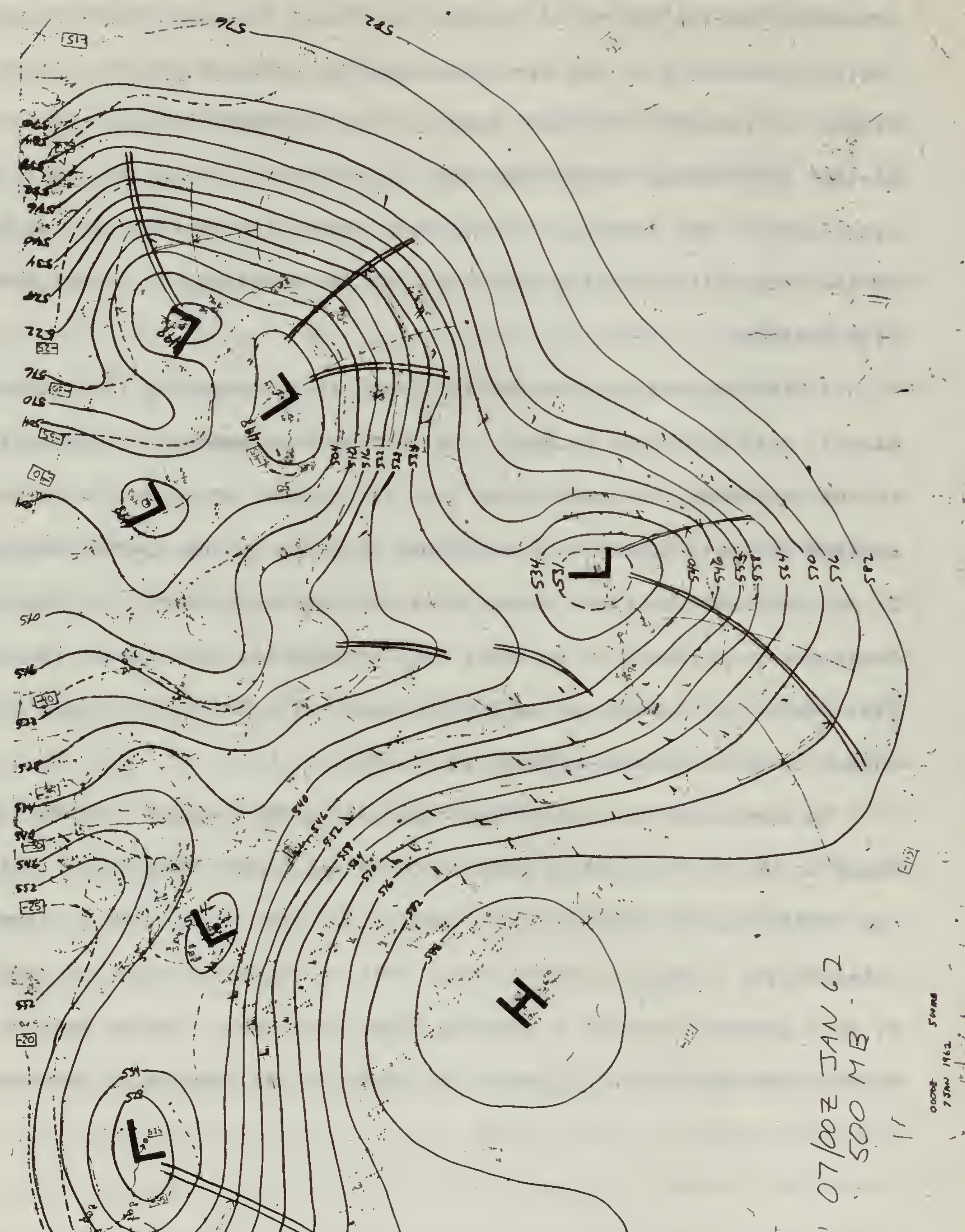

Fig. 3

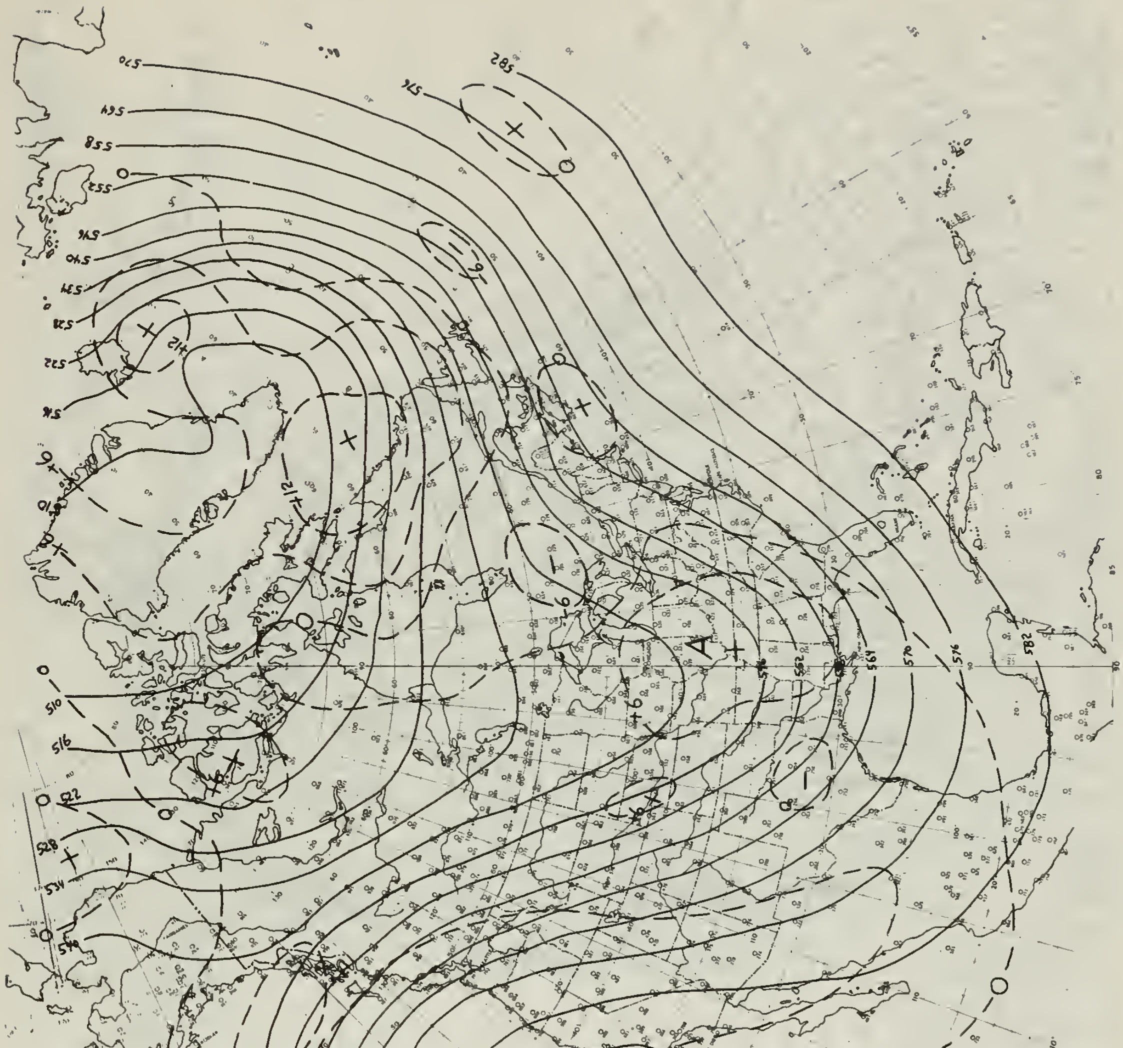
NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
FOR 500 MB
07/00Z JAN 62

Fig. 4

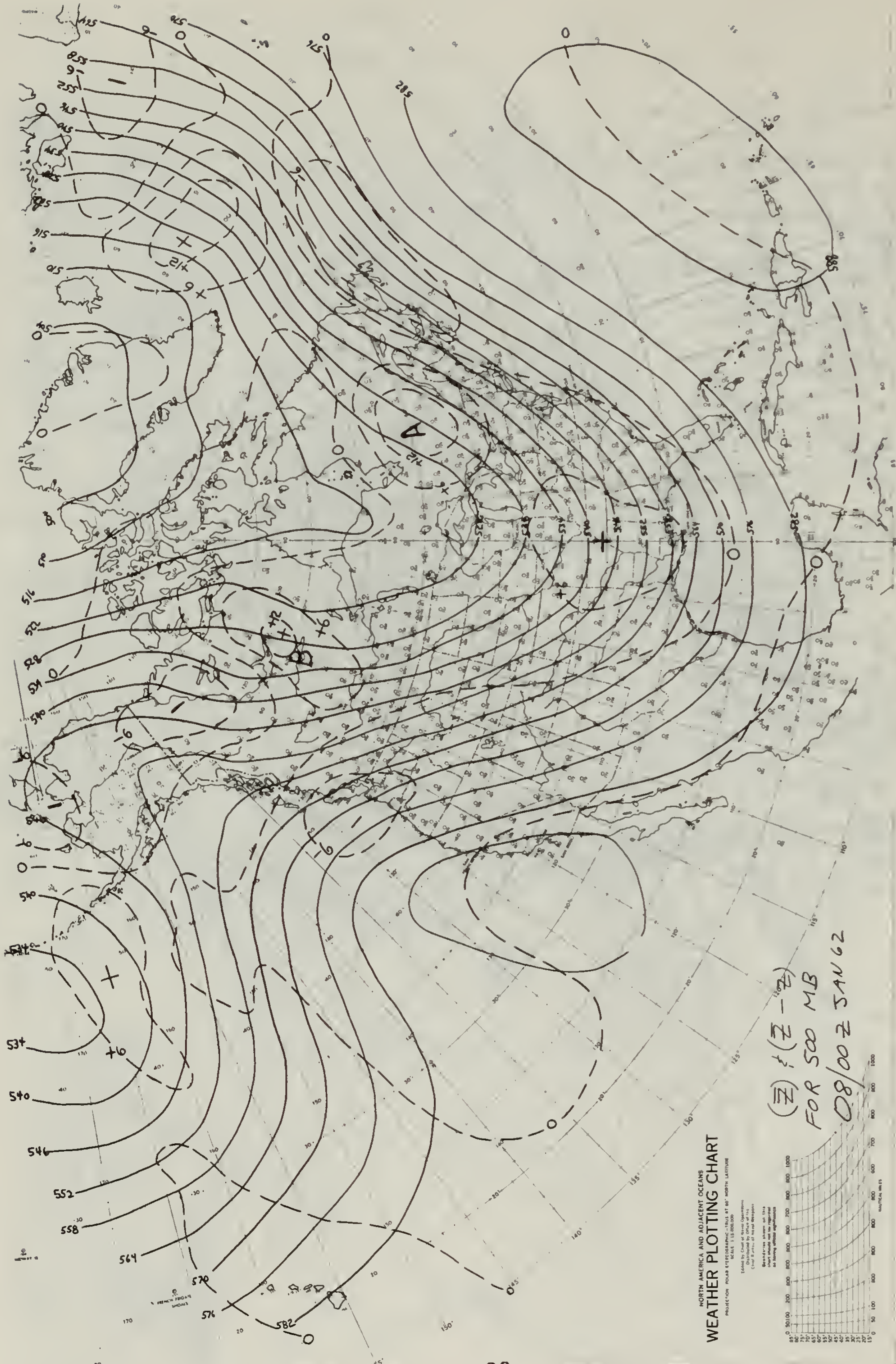
NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
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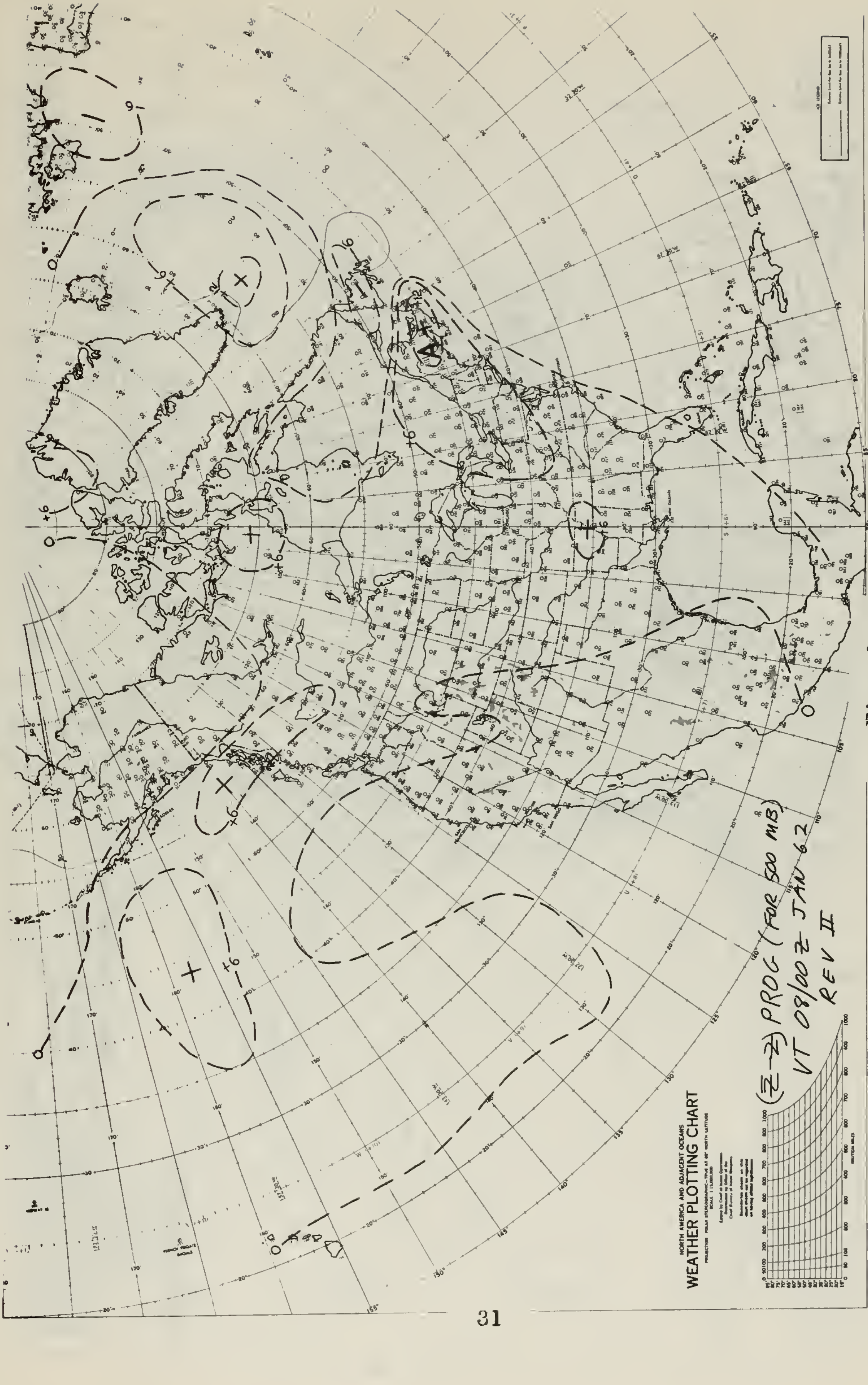
Fig. 5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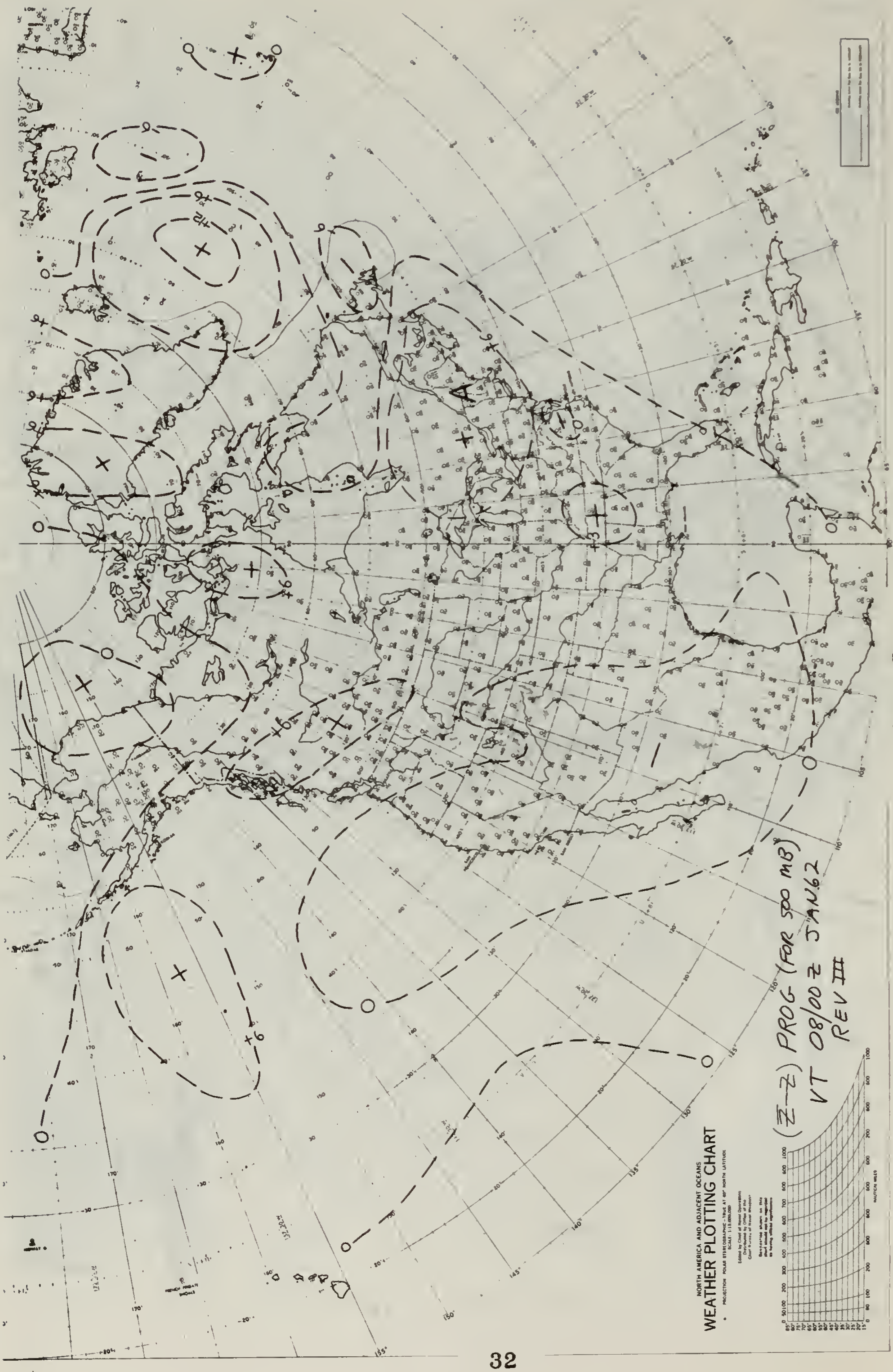
REV II

Fig. 6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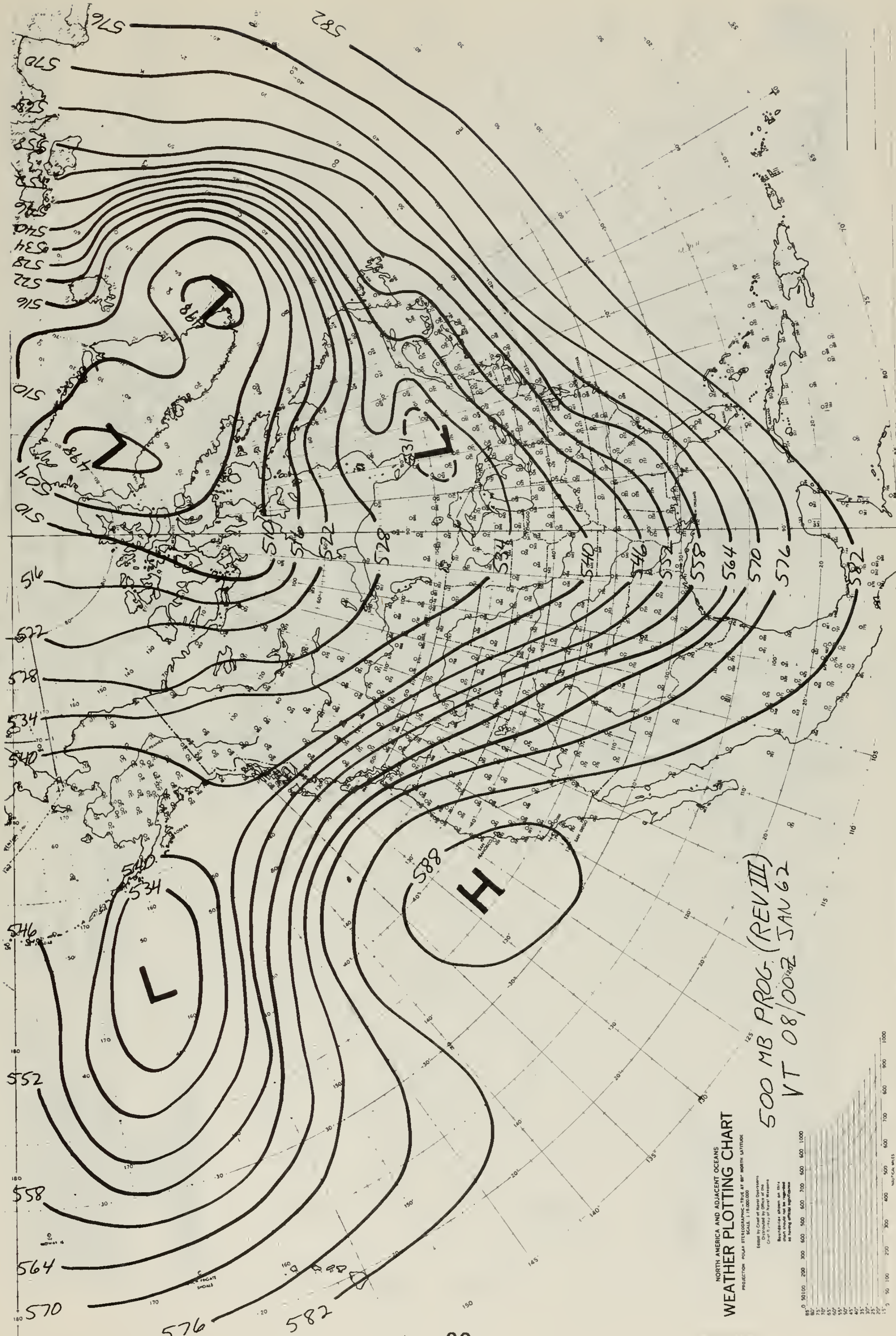
REV III

Fig. 7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NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART

Fig. 8

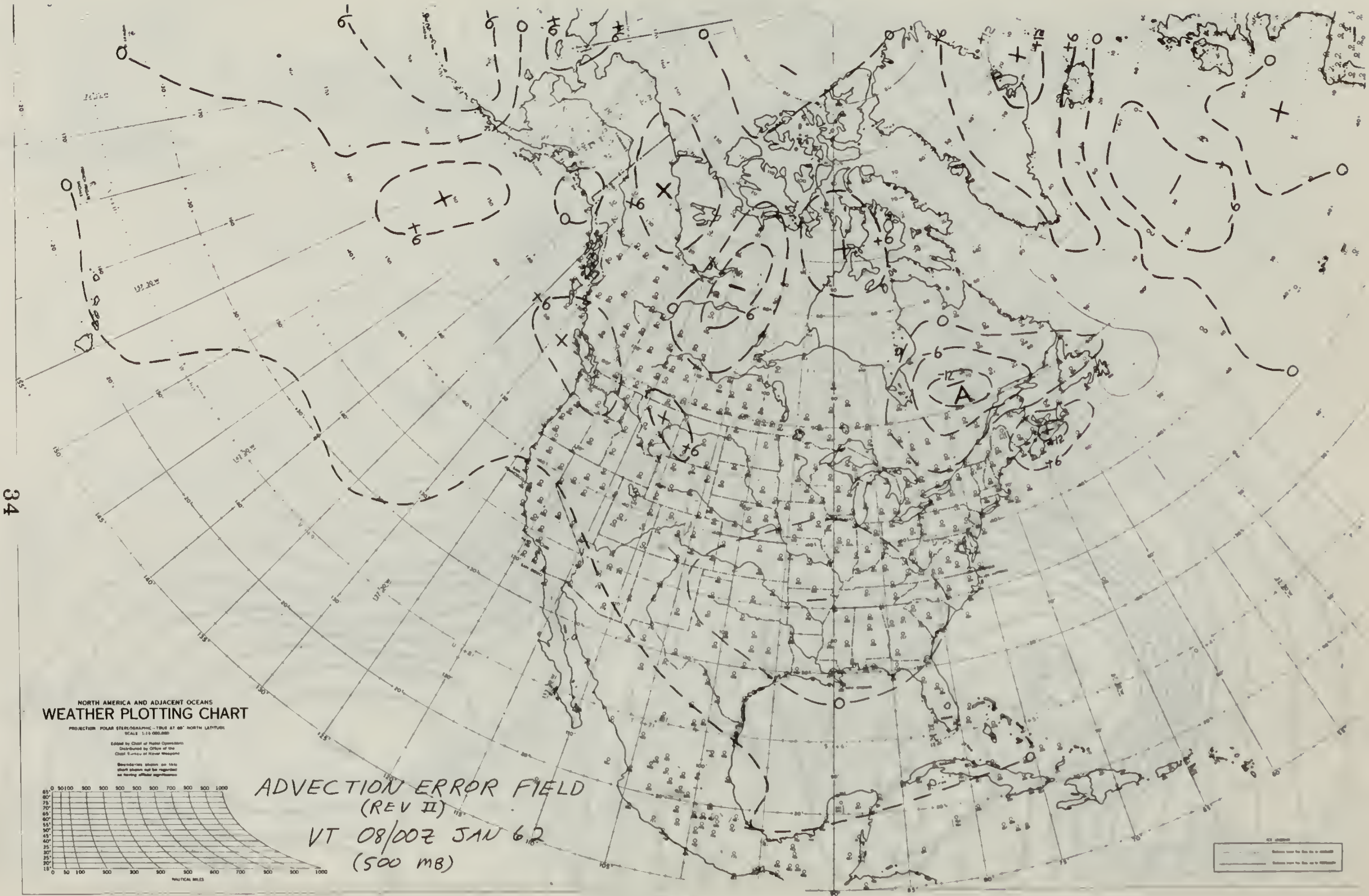
NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
ADVECTION ERROR FIELD
(REV II)
VT 08/00Z JAN 62
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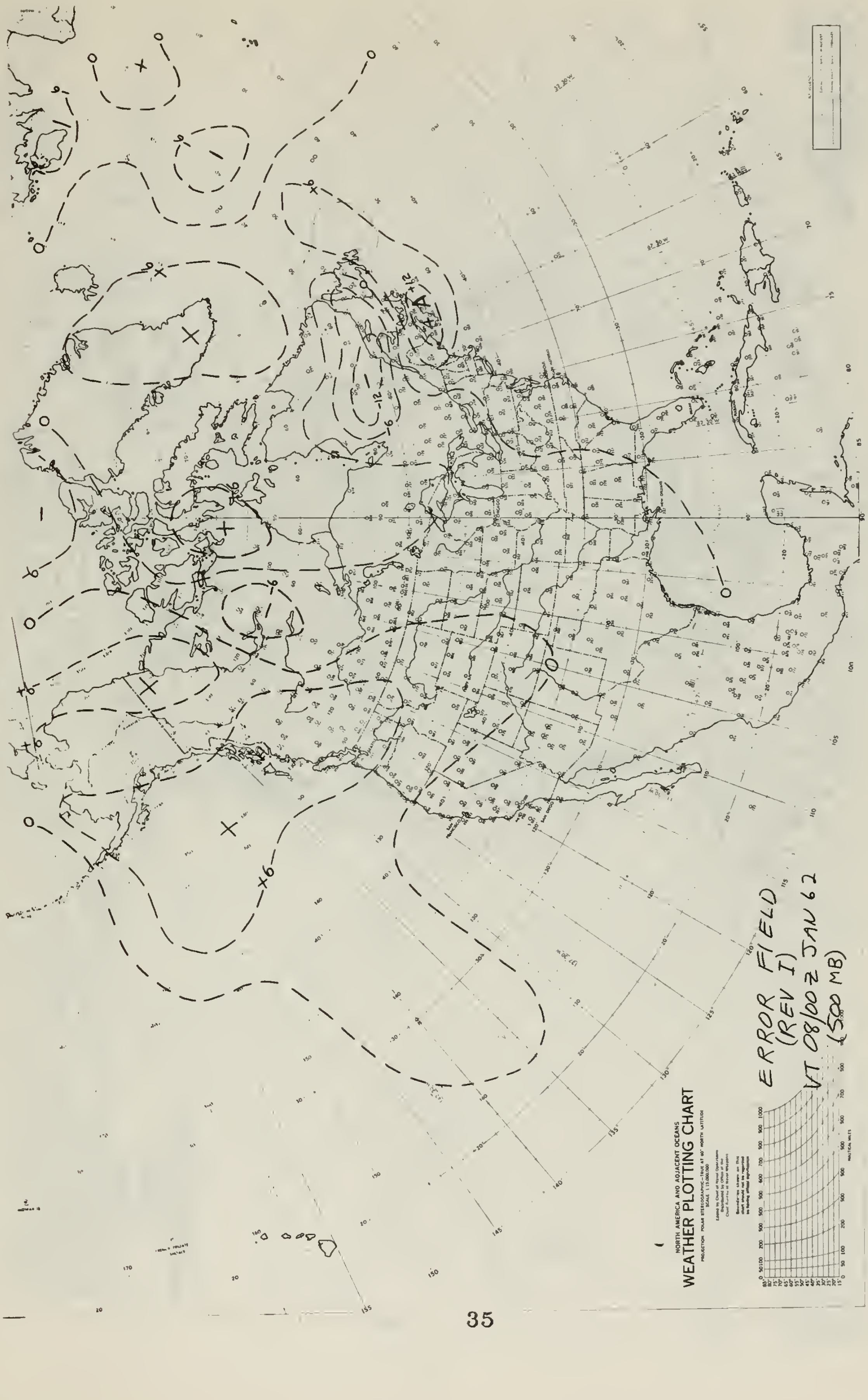
Fig. 9



NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
ERROR FIELD
(REV I)
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(500 MB)

Fig. 10

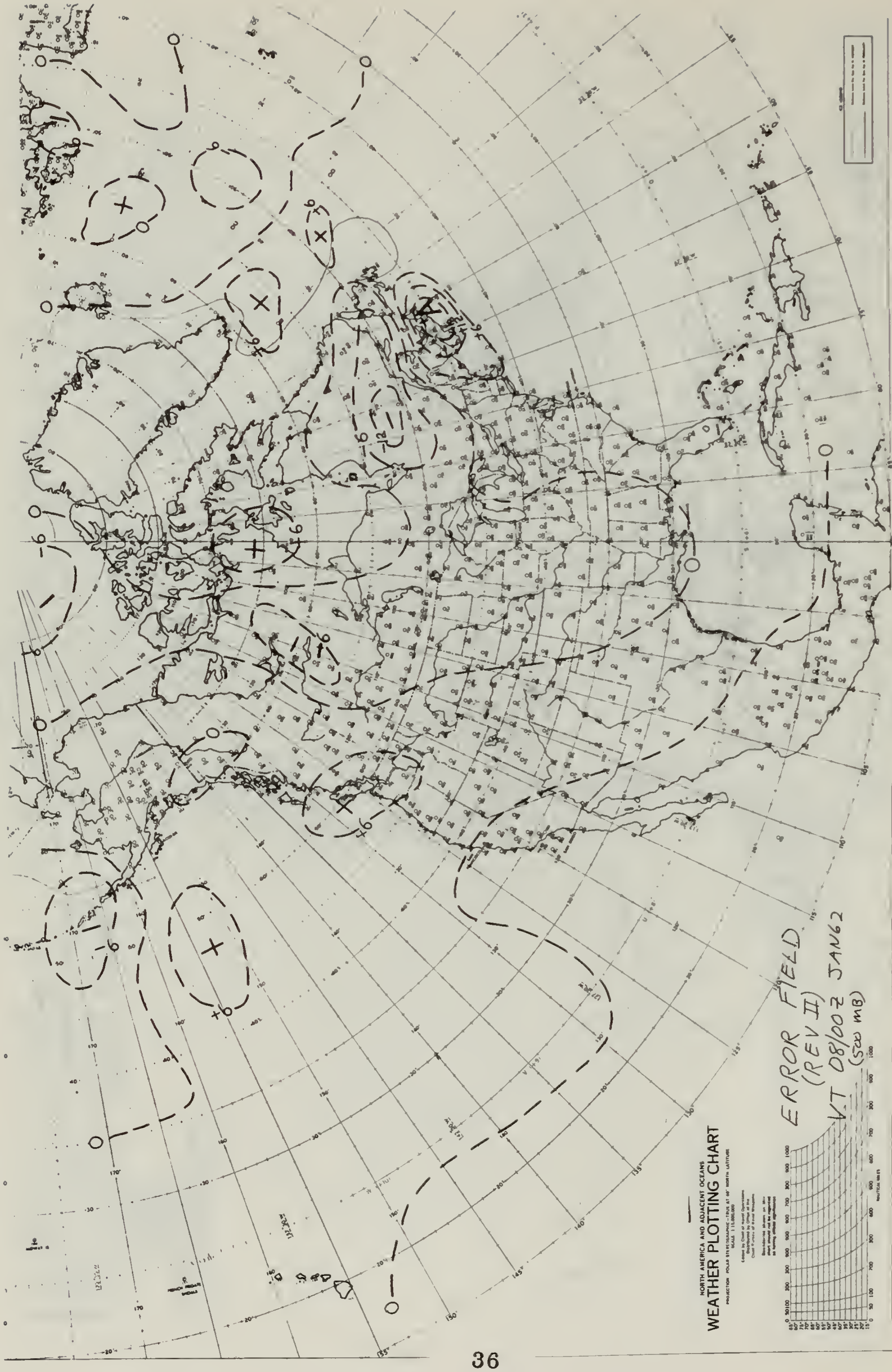

NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
ERROR FIELD
(REV II)
VT 08/00Z JAN62
(500 mB)

Fig. 11

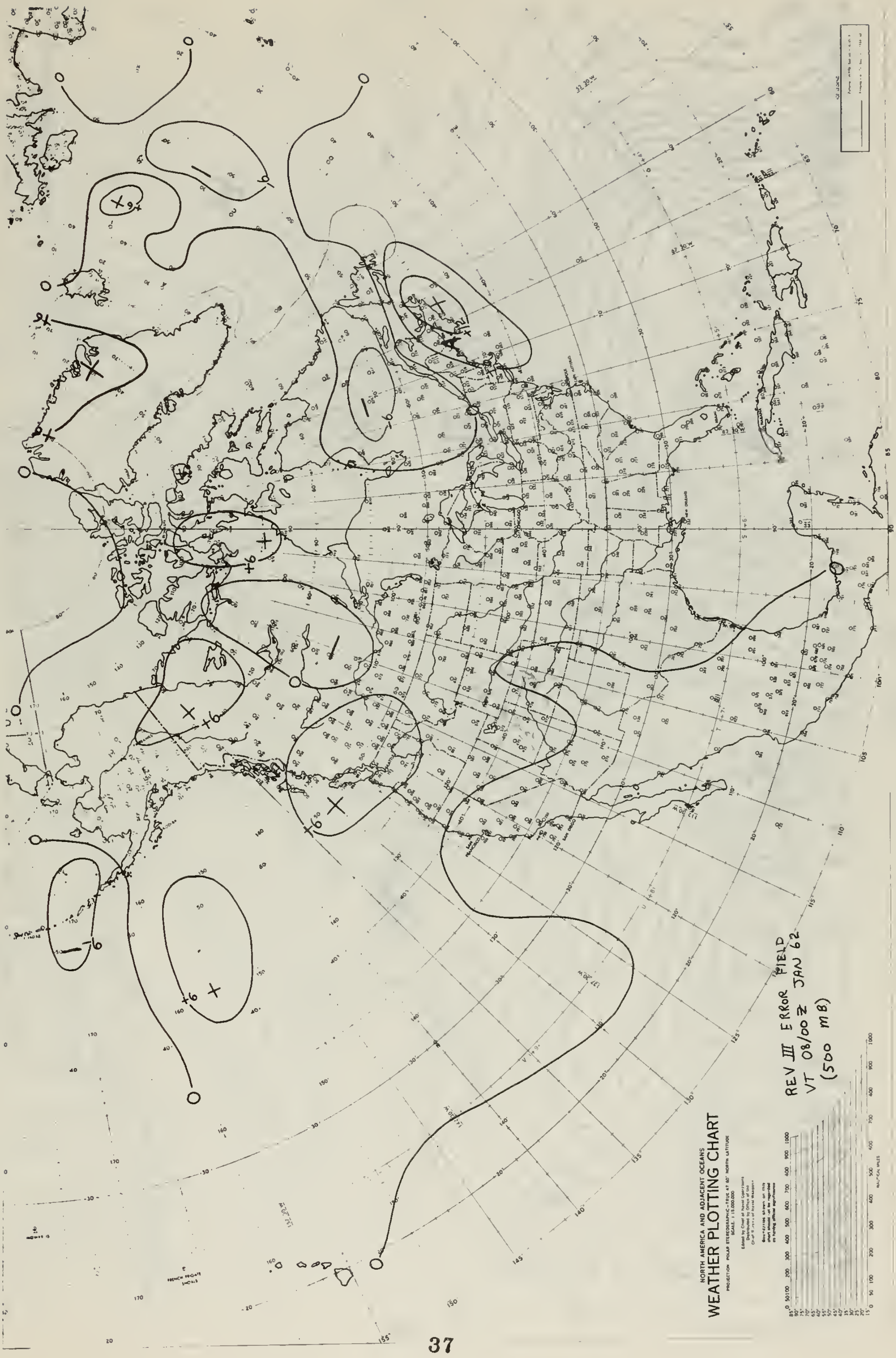

NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
REV III ERROR FIELD
VT 08/00Z JAN 62
(500 MB)

Fig. 12

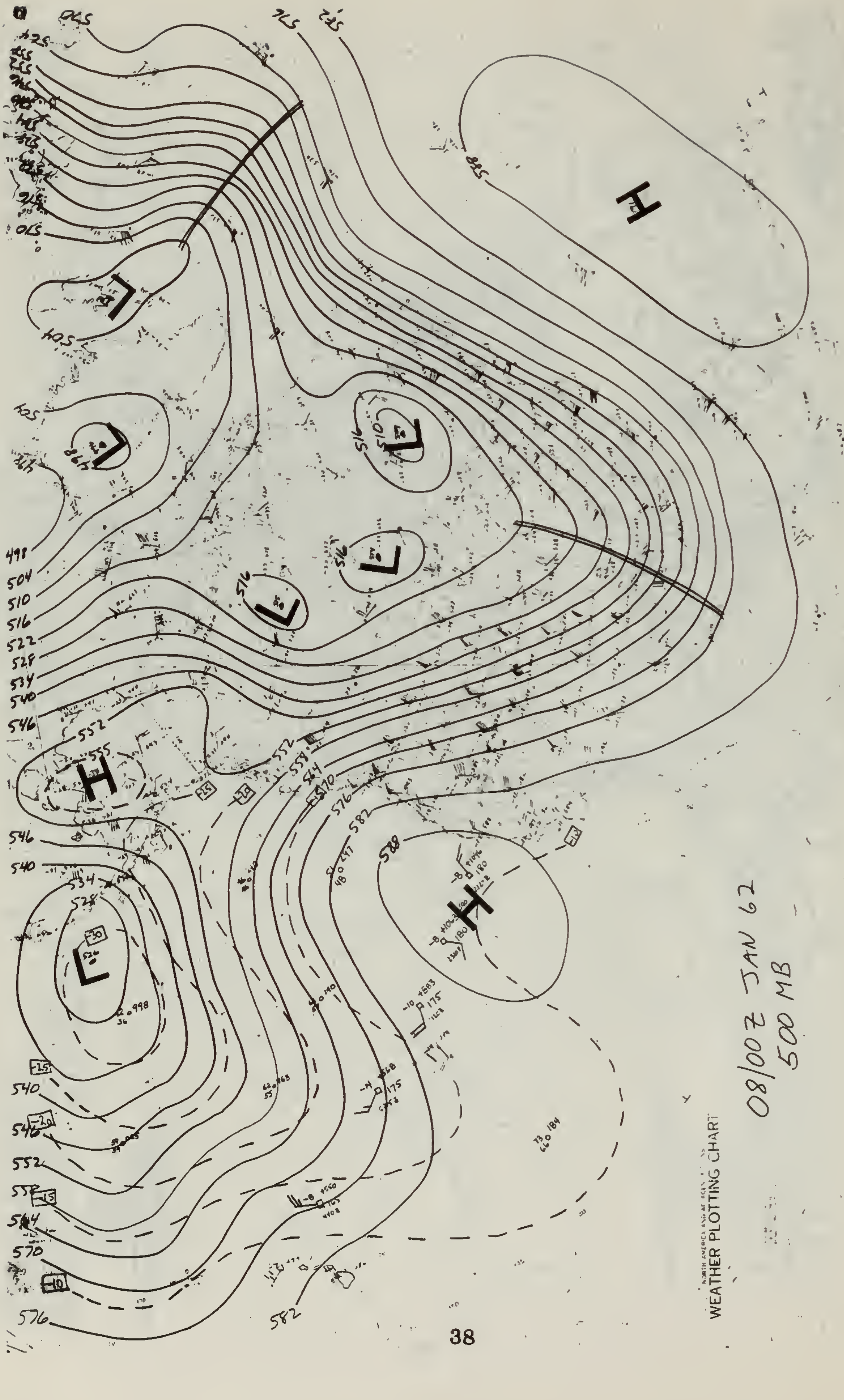


Fig. 13

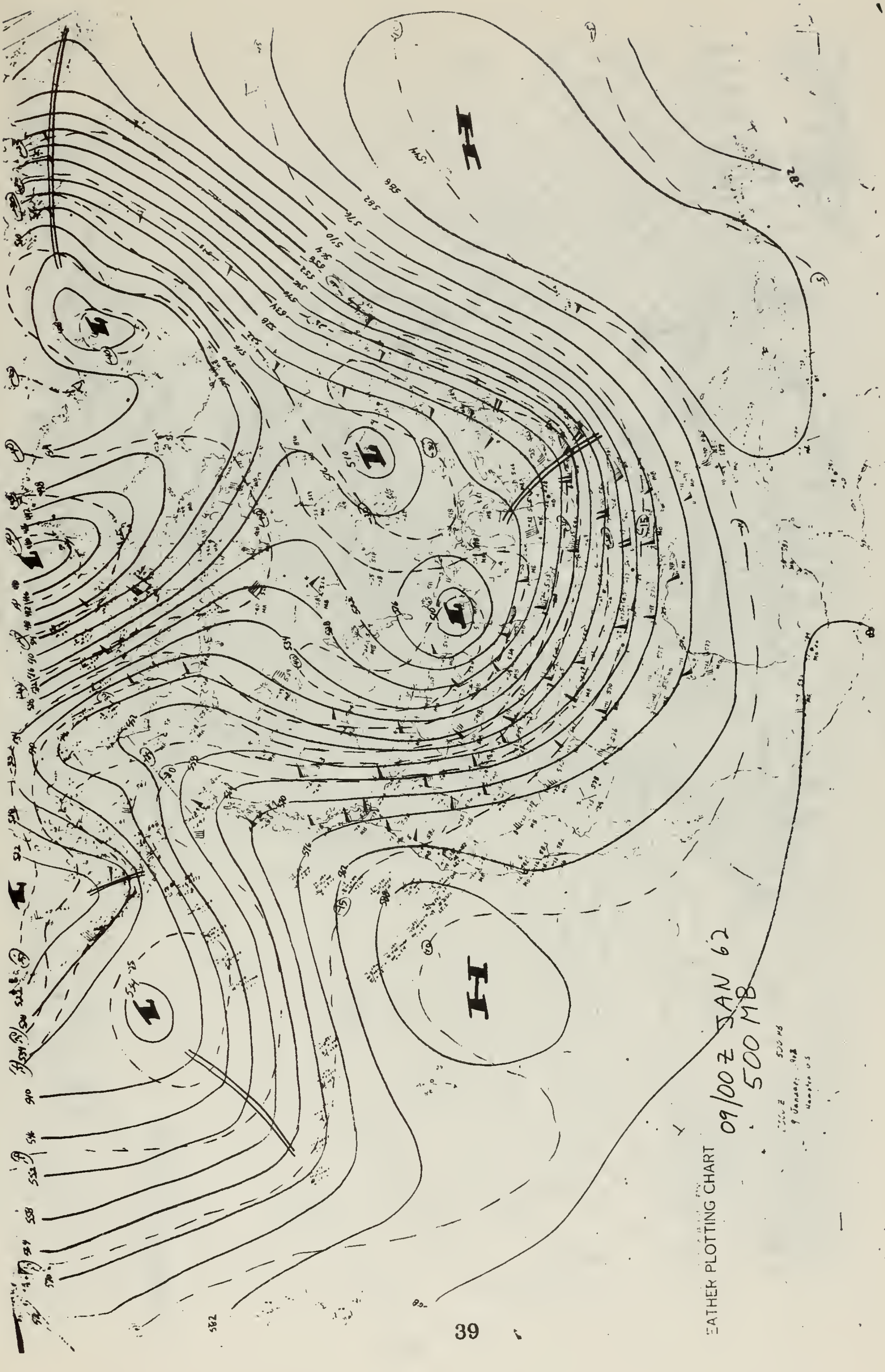


Fig. 14

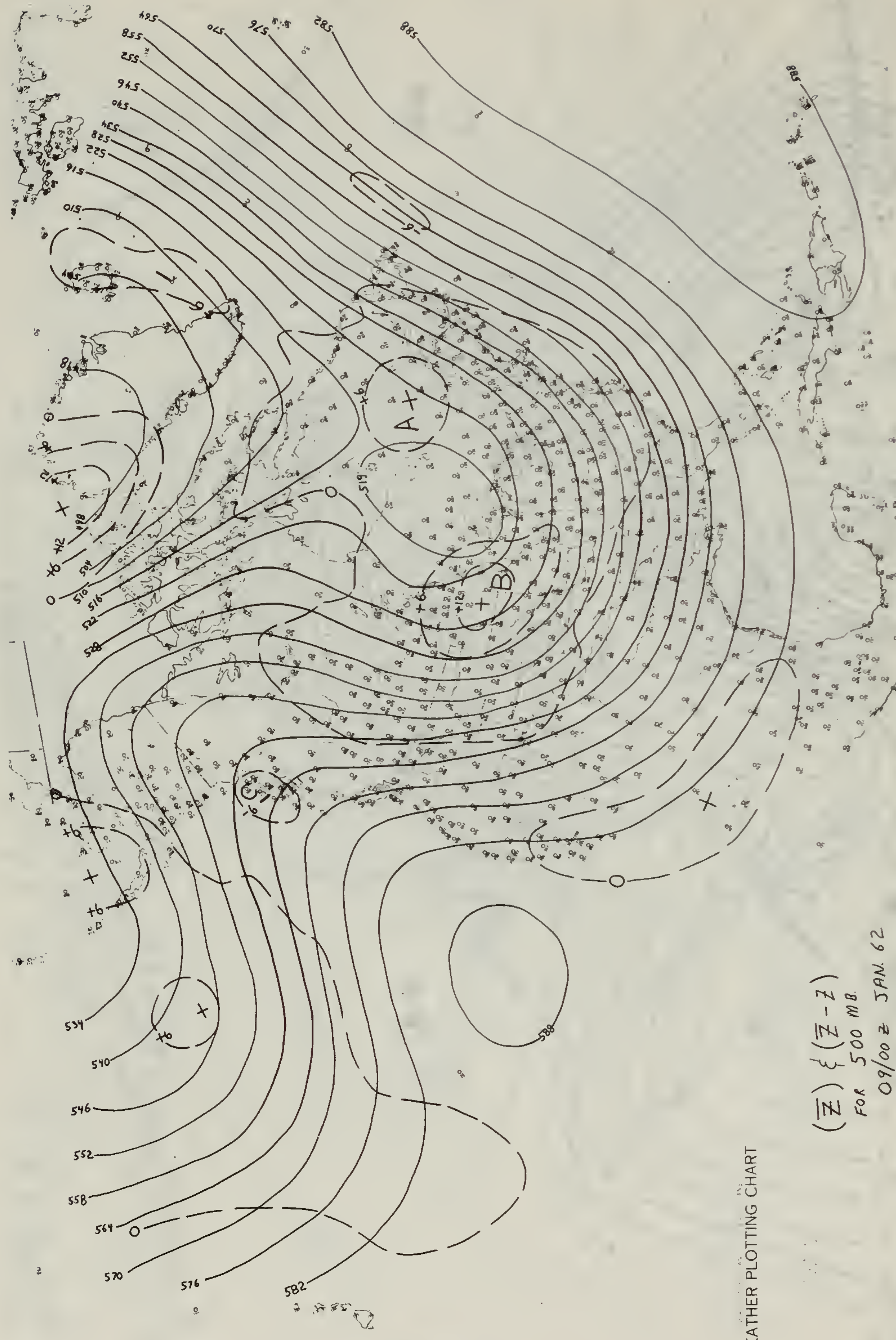

$(\overline{Z})$ $\xi(\overline{Z}-Z)$
FOR 500 MB
09/00 Z JAN. 62
WEATHER PLOTTING CHART
A
B
588
582
576
570
564
558
552
546
540
534
528
522
516
510
504
519

Fig. 15

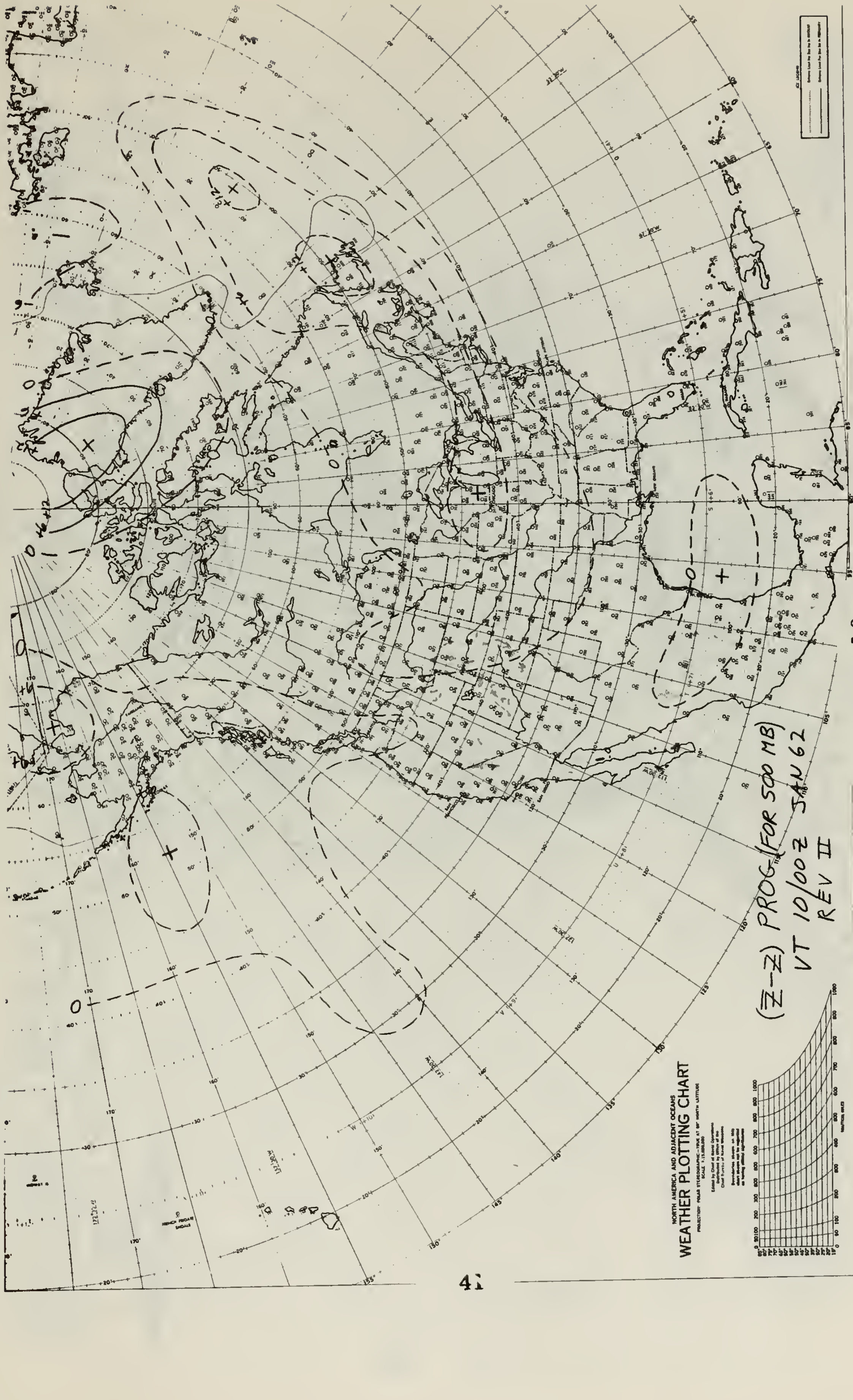

NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
(Z̄-Z) PROG (FOR 500 MB)
VT 10/00Z JAN 62
REV II

Fig. 16

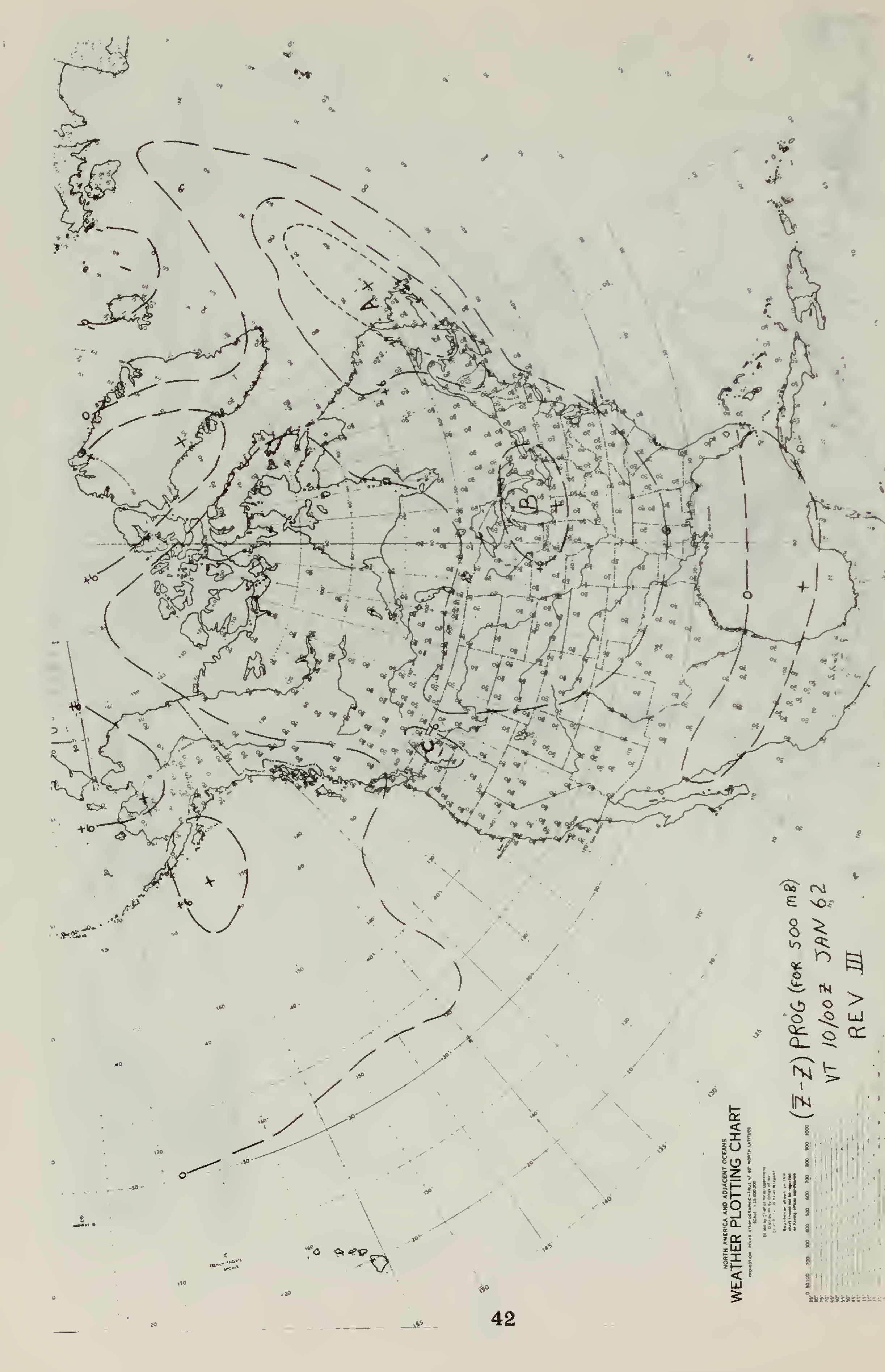

NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
($\bar{Z}$-Z) PROG (FOR 500 mb)
VT 10/00Z JAN 62
REV III

Fig. 17

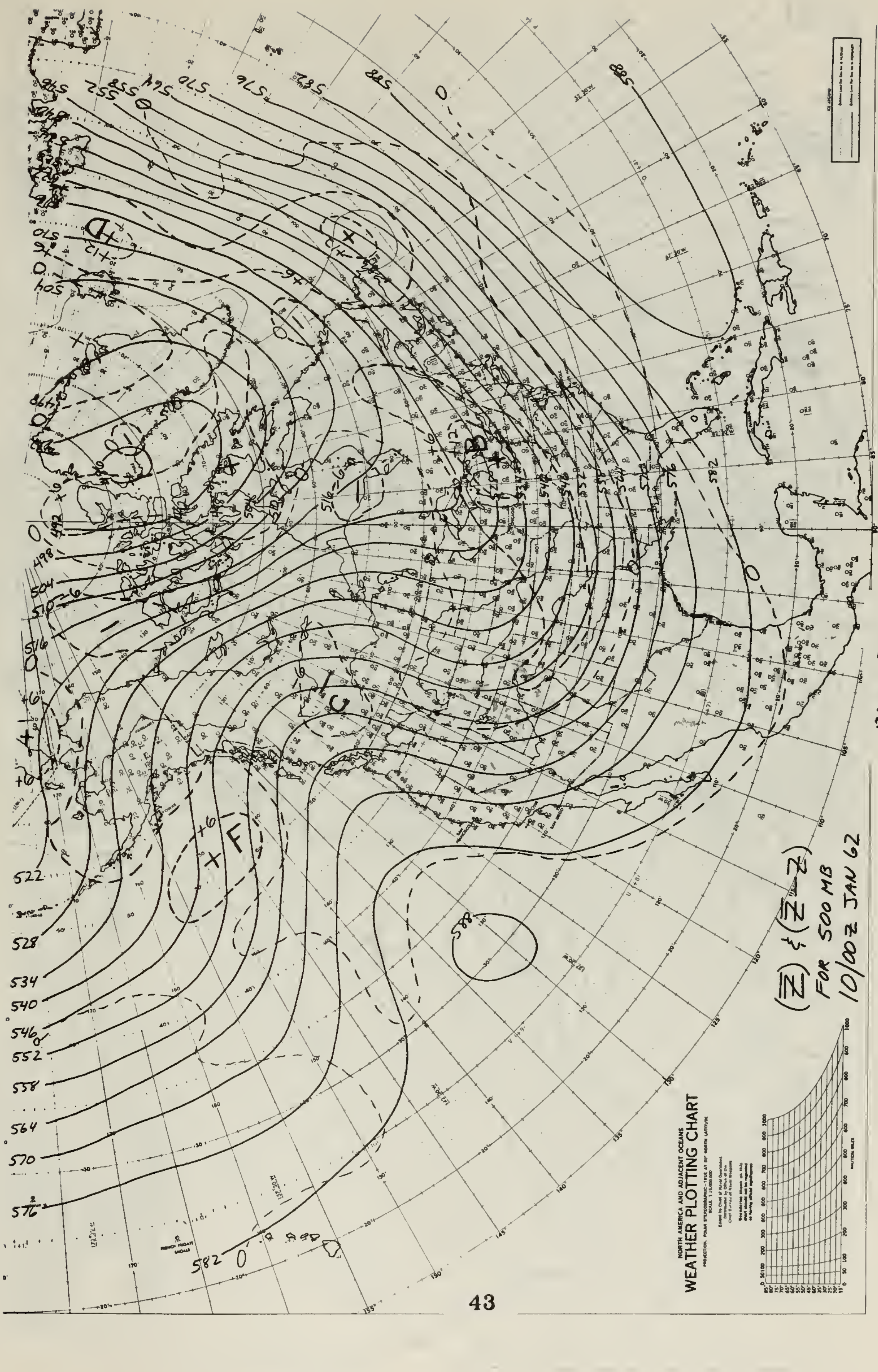

NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
FOR 500 MB
10/00Z JAN 62

Fig. 18

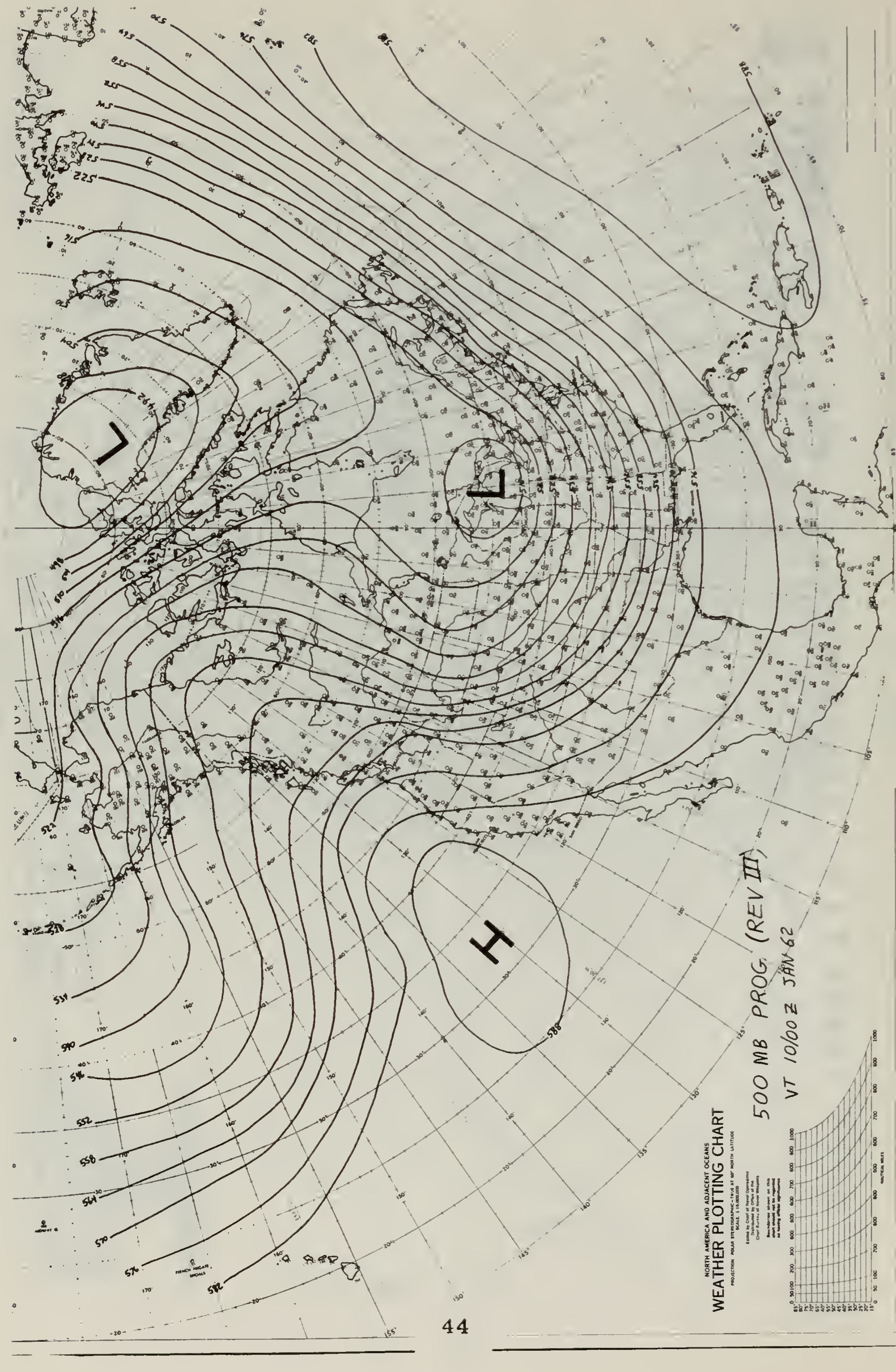

NORTH AMERICA AND ADJACENT OCEANS
WEATHER PLOTTING CHART
500 MB PROG. (REV III)
VT 10/00 Z JAN 62
L
L
H

Fig. 19

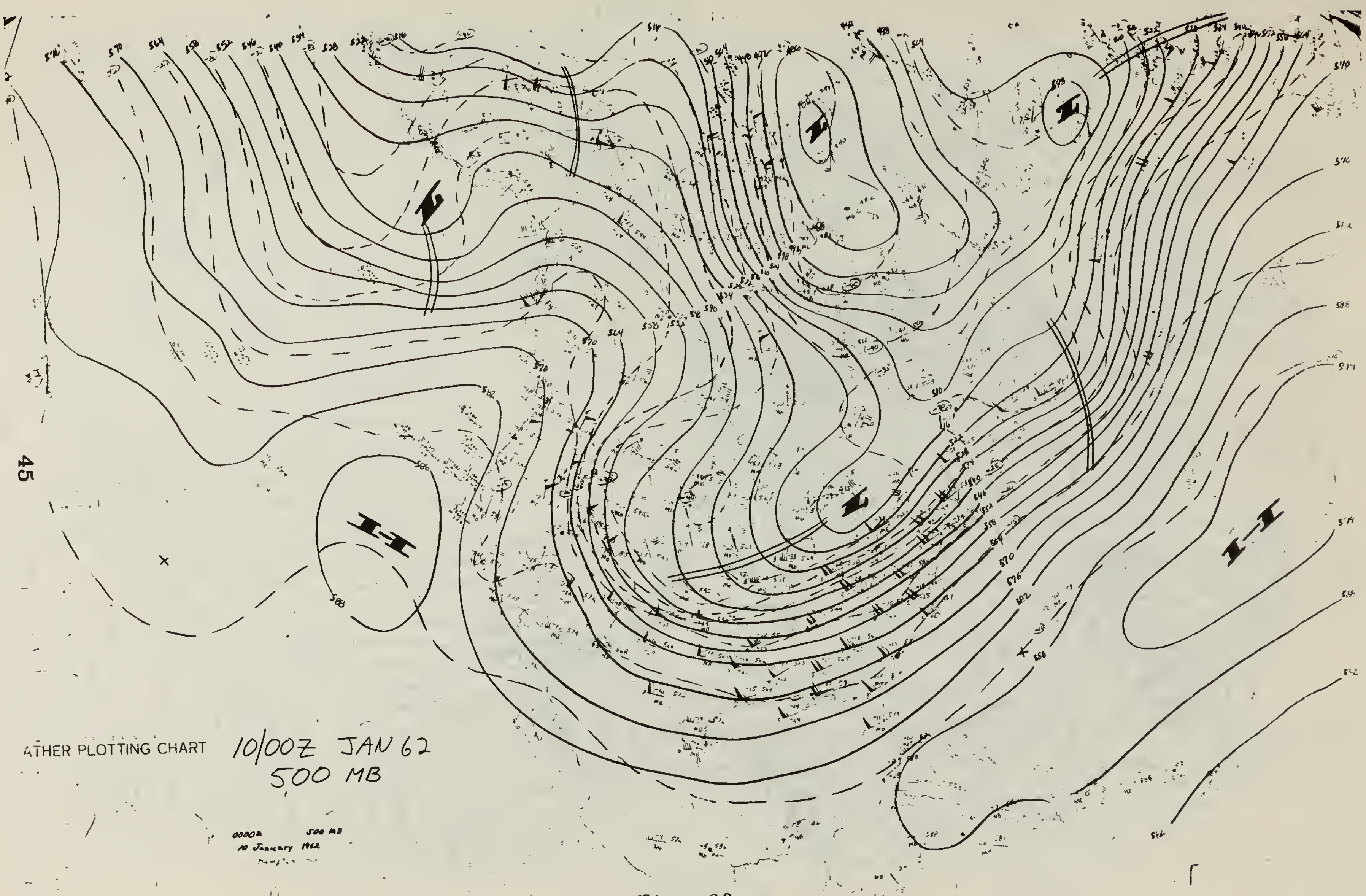

ATHER PLOTTING CHART
10/00Z JAN 62
500 MB
0000Z 500 MB
10 January 1962

Fig. 20

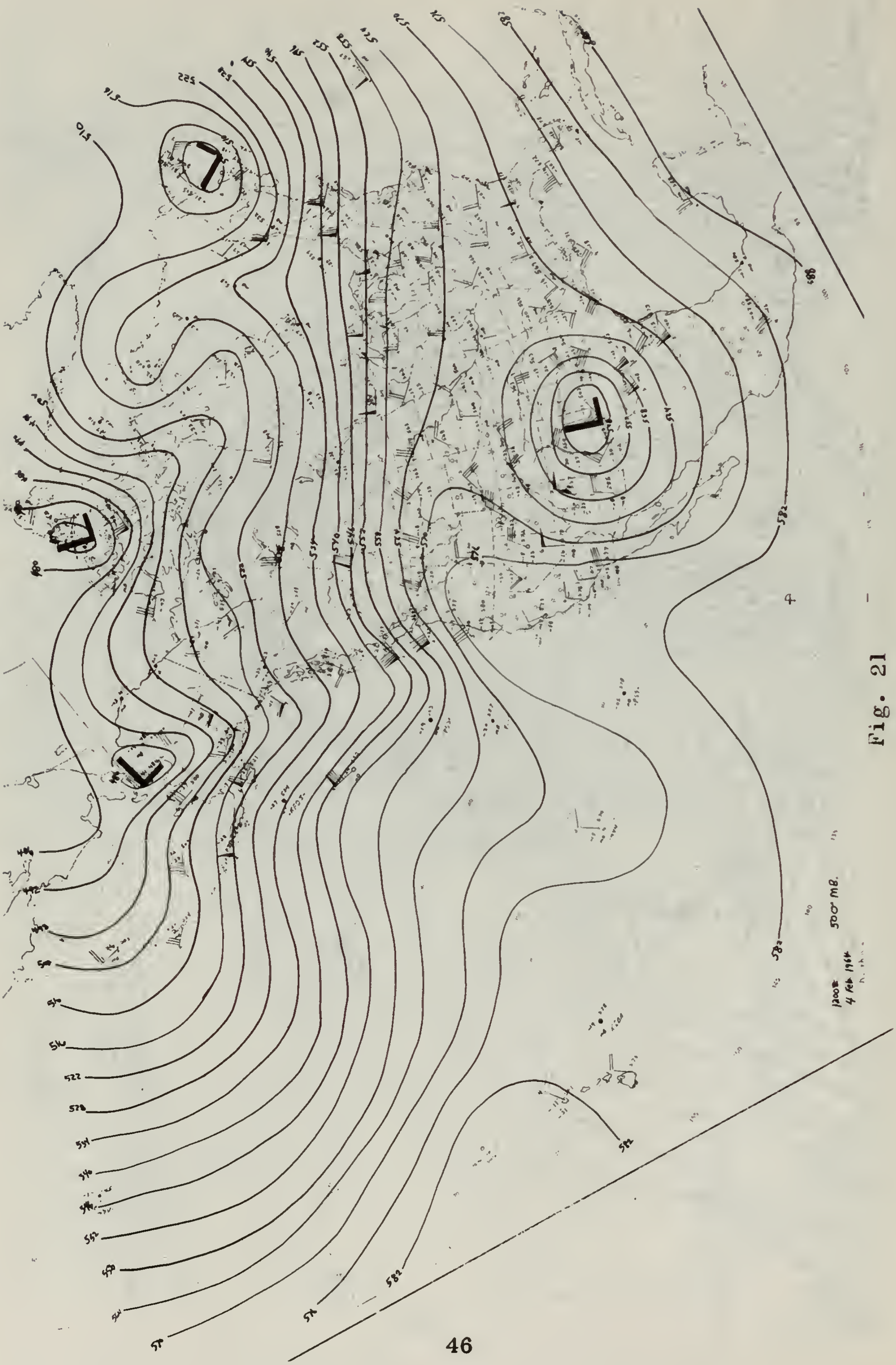


Fig. 21

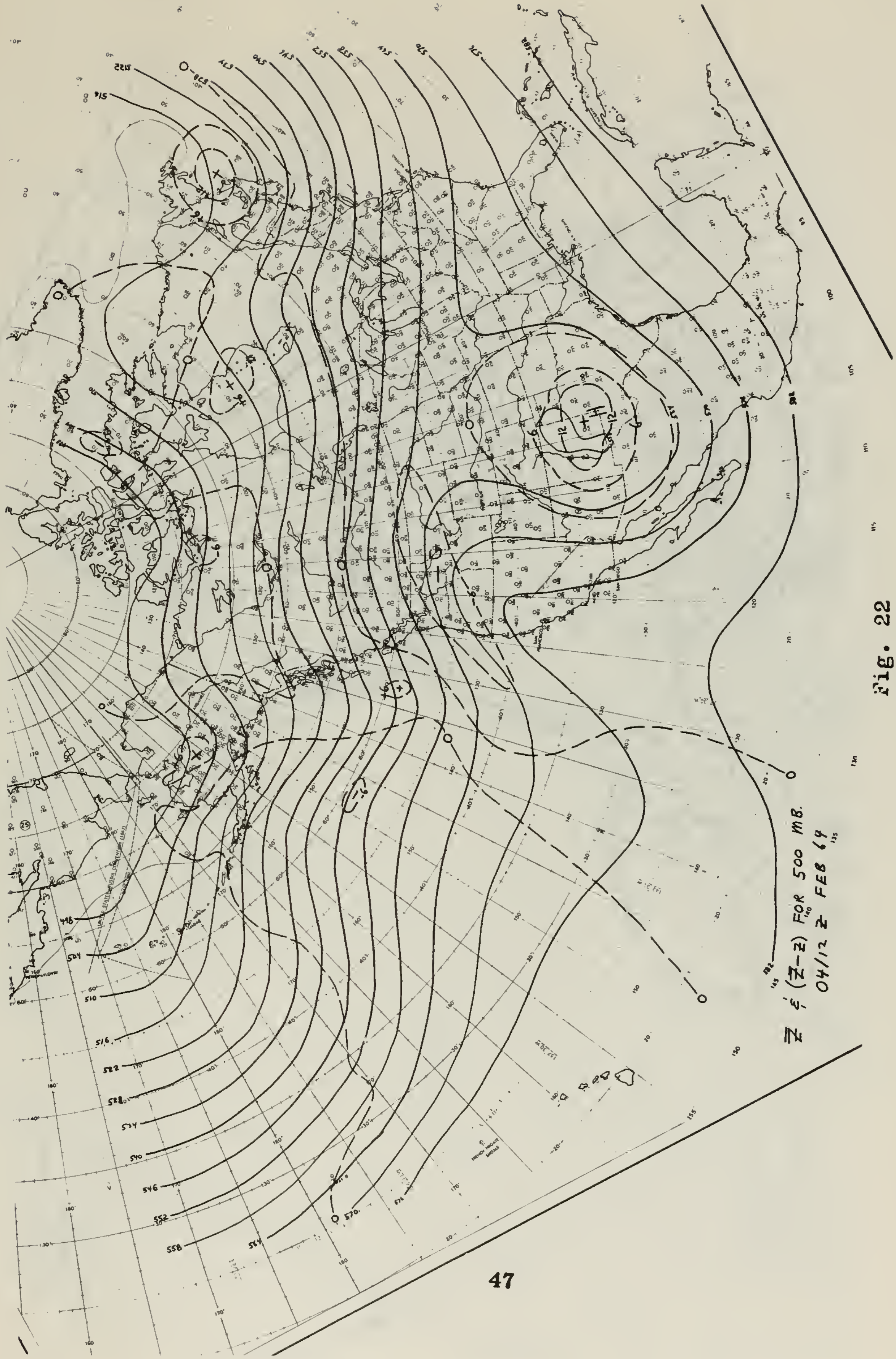
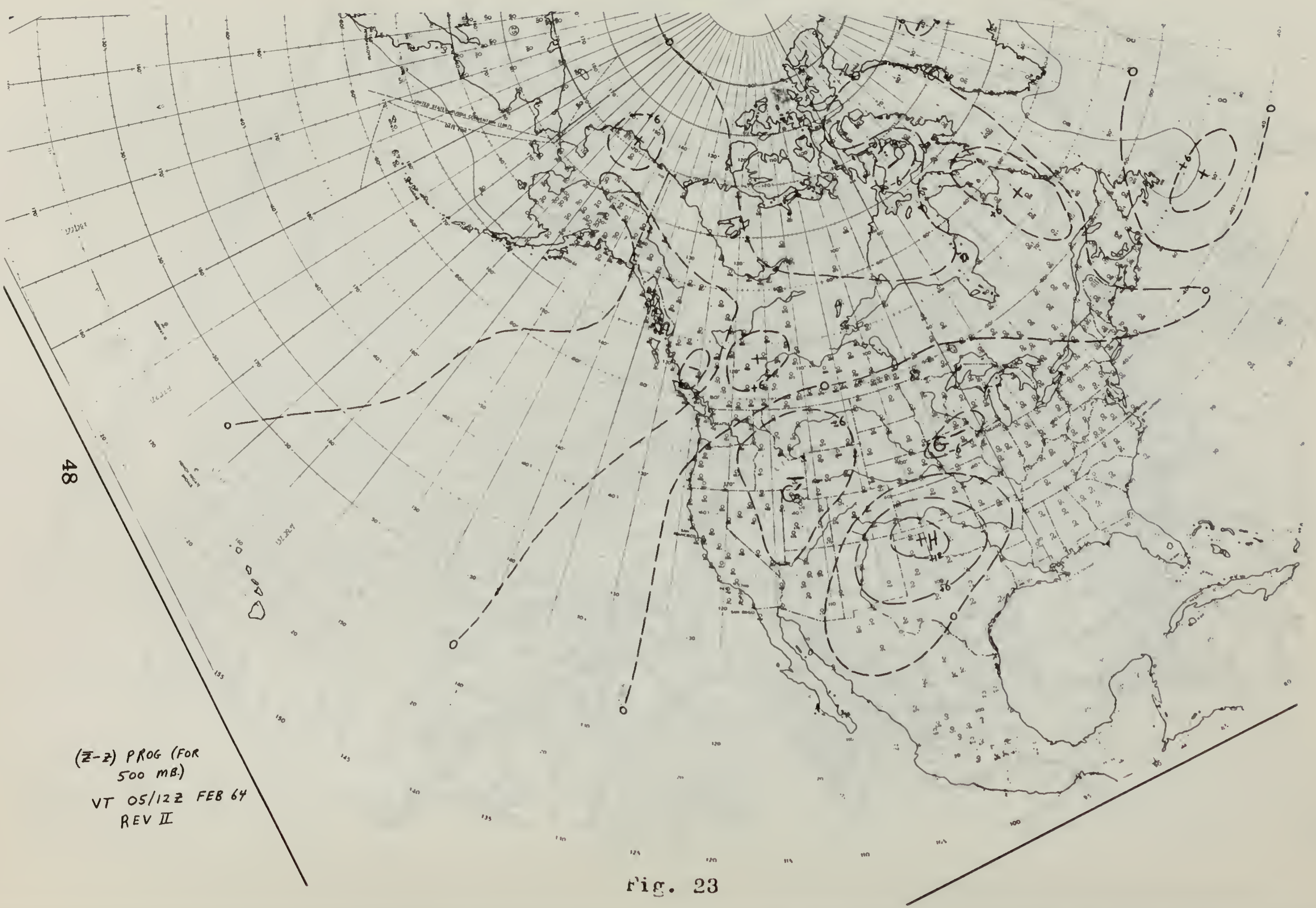


Fig. 22



(Z̄-Z) PROG (FOR
500 MB.)
VT 05/12Z FEB 64
REV II

Fig. 23

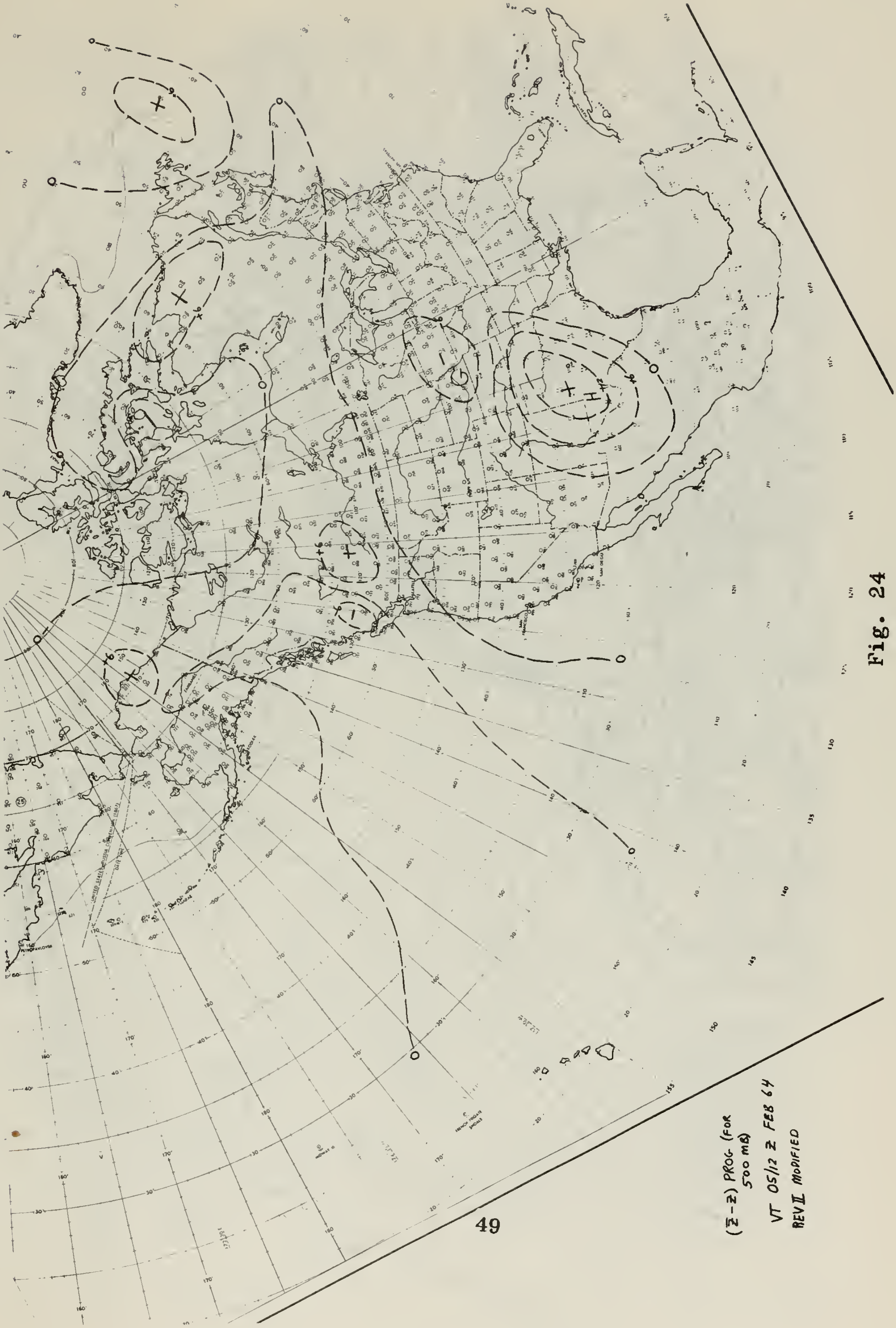


Fig. 24

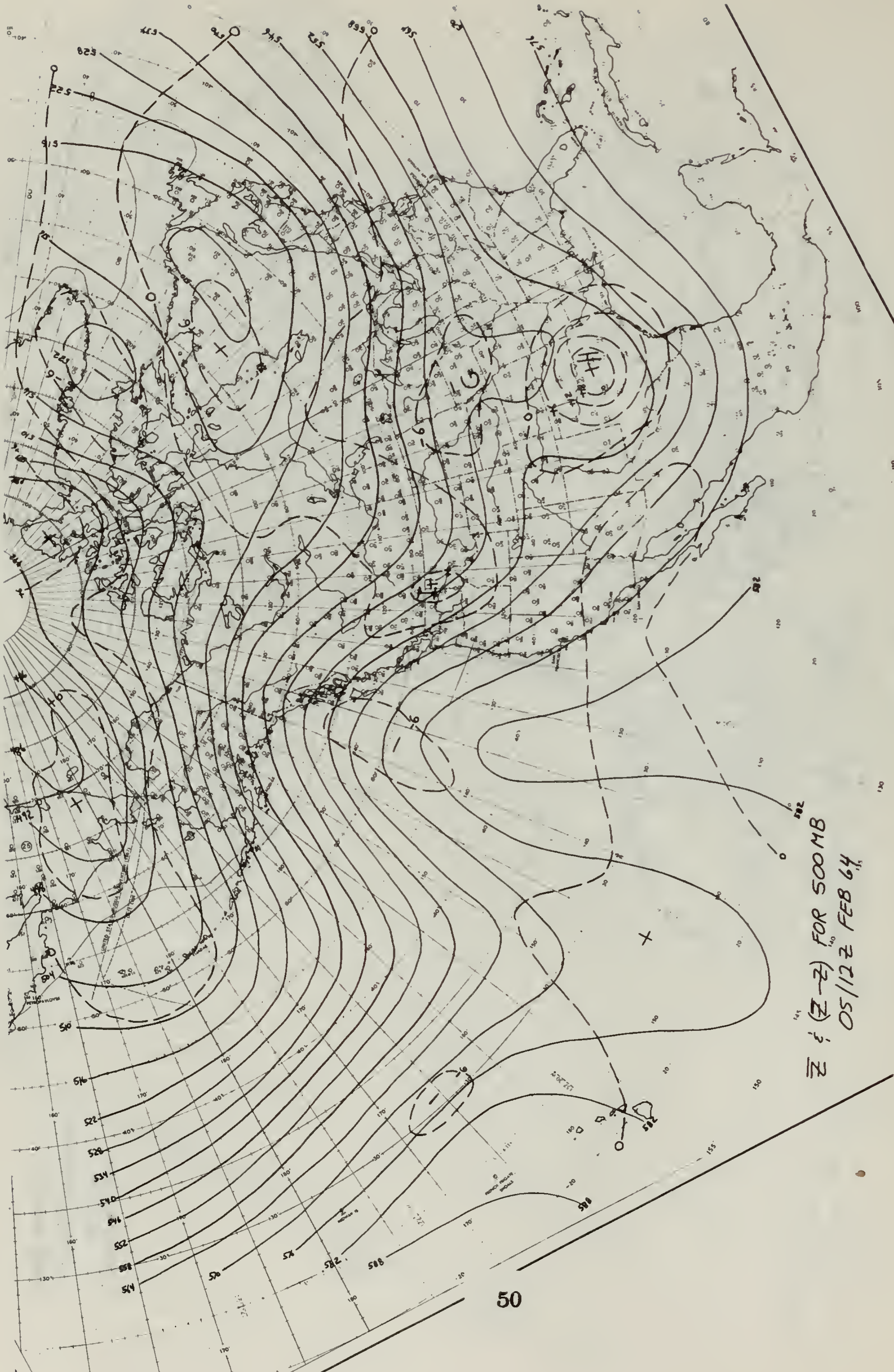


Fig. 25

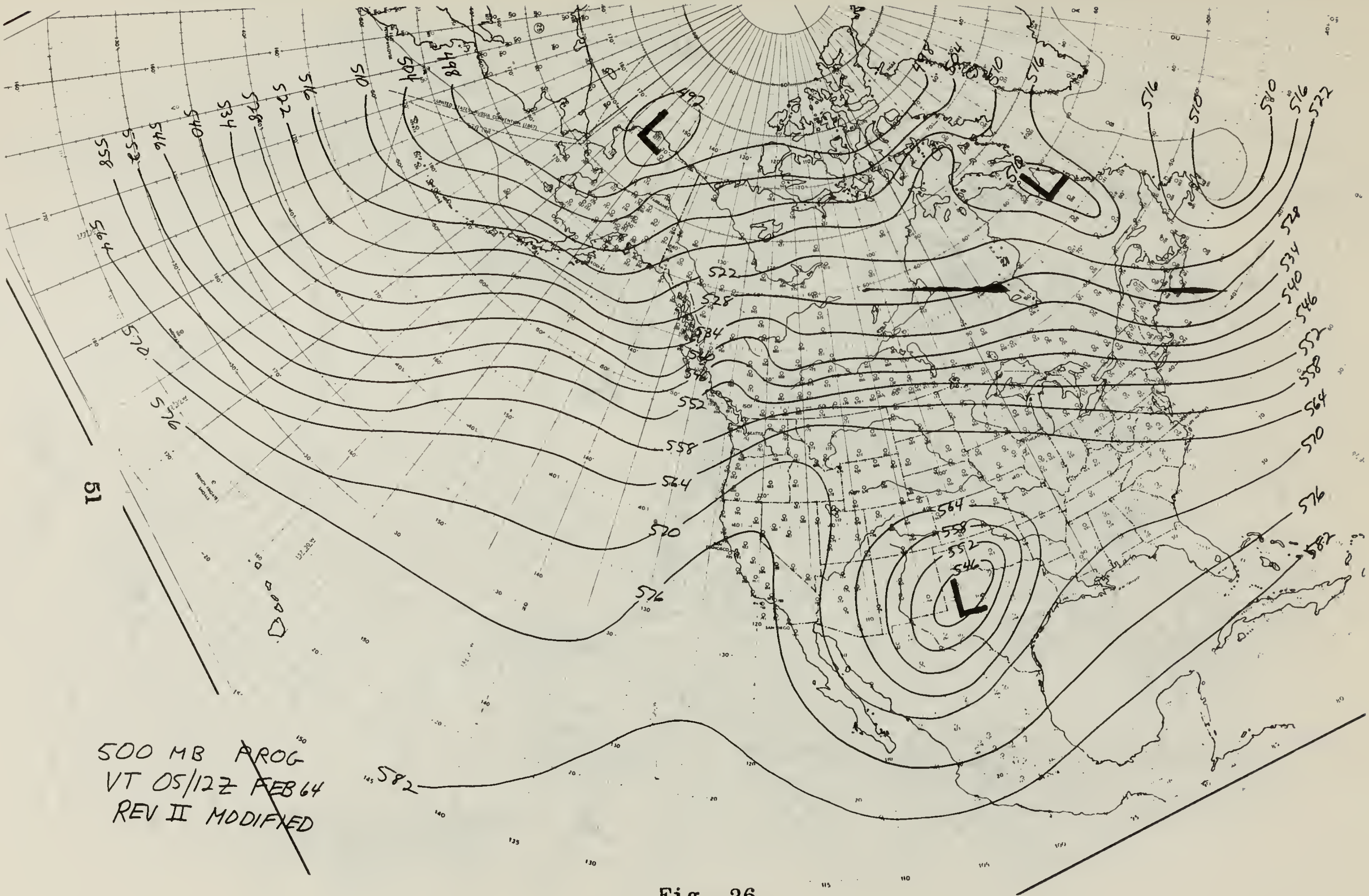


Fig. 26

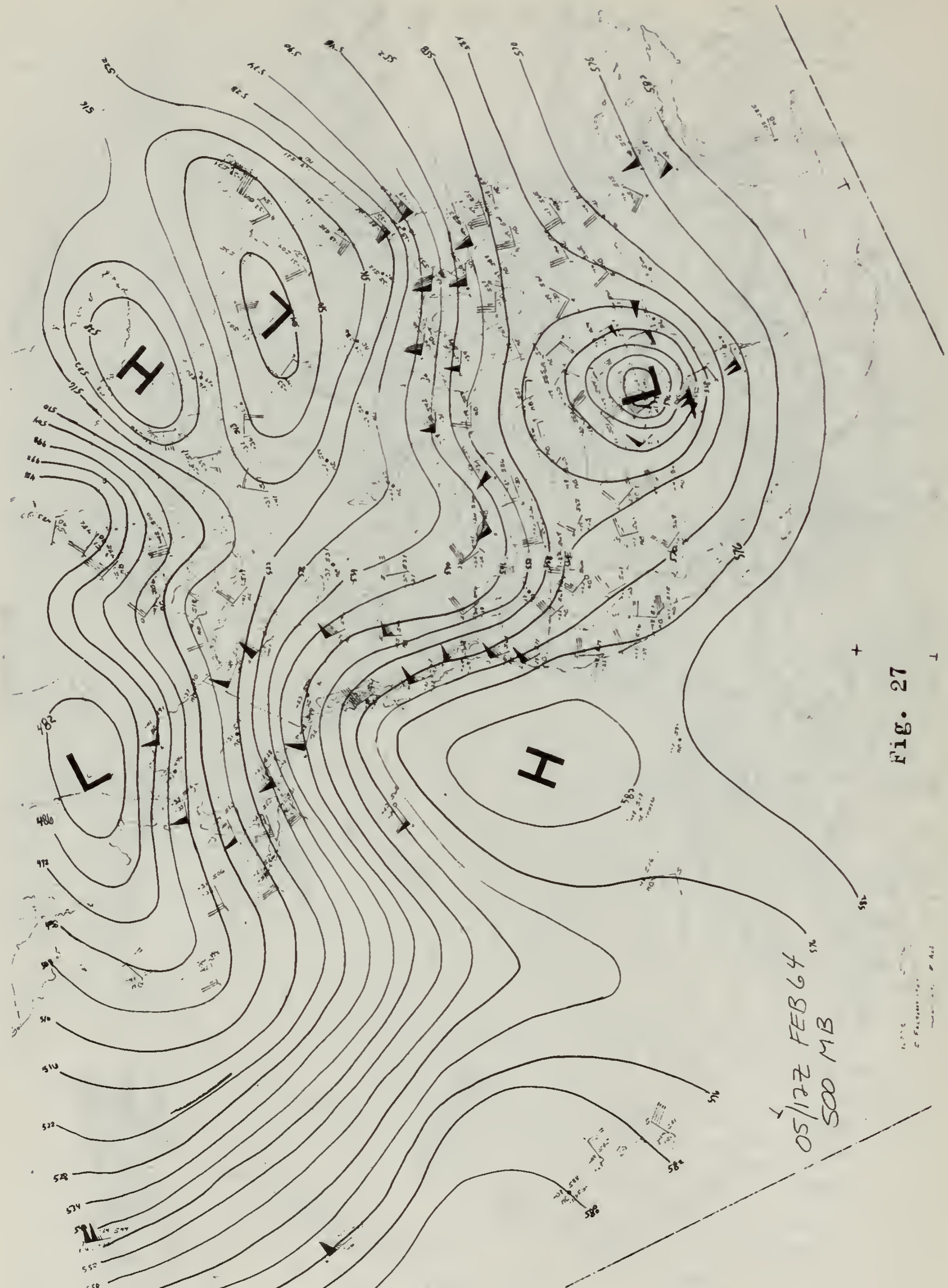


Fig. 27

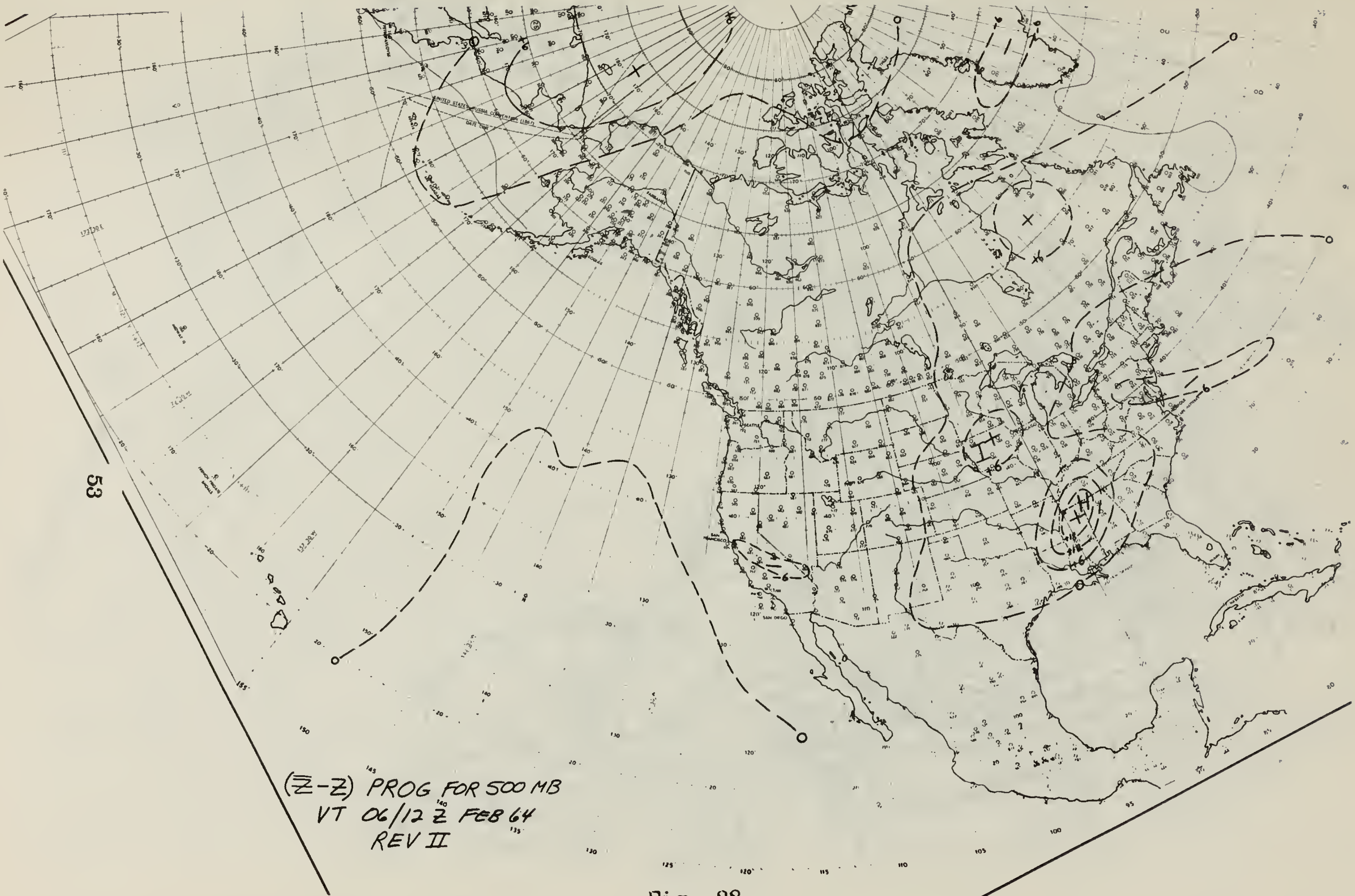


Fig. 28

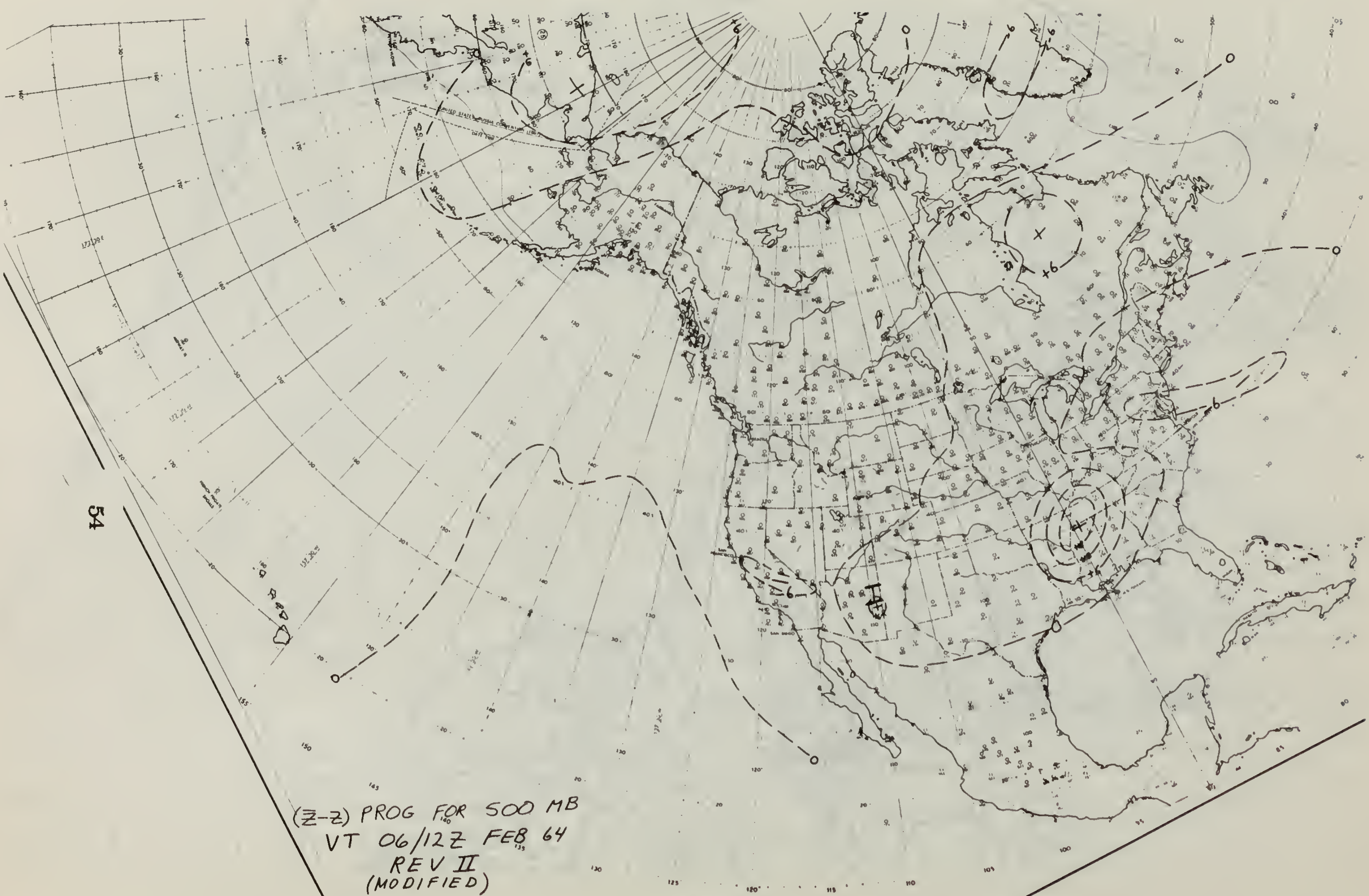


Fig. 29

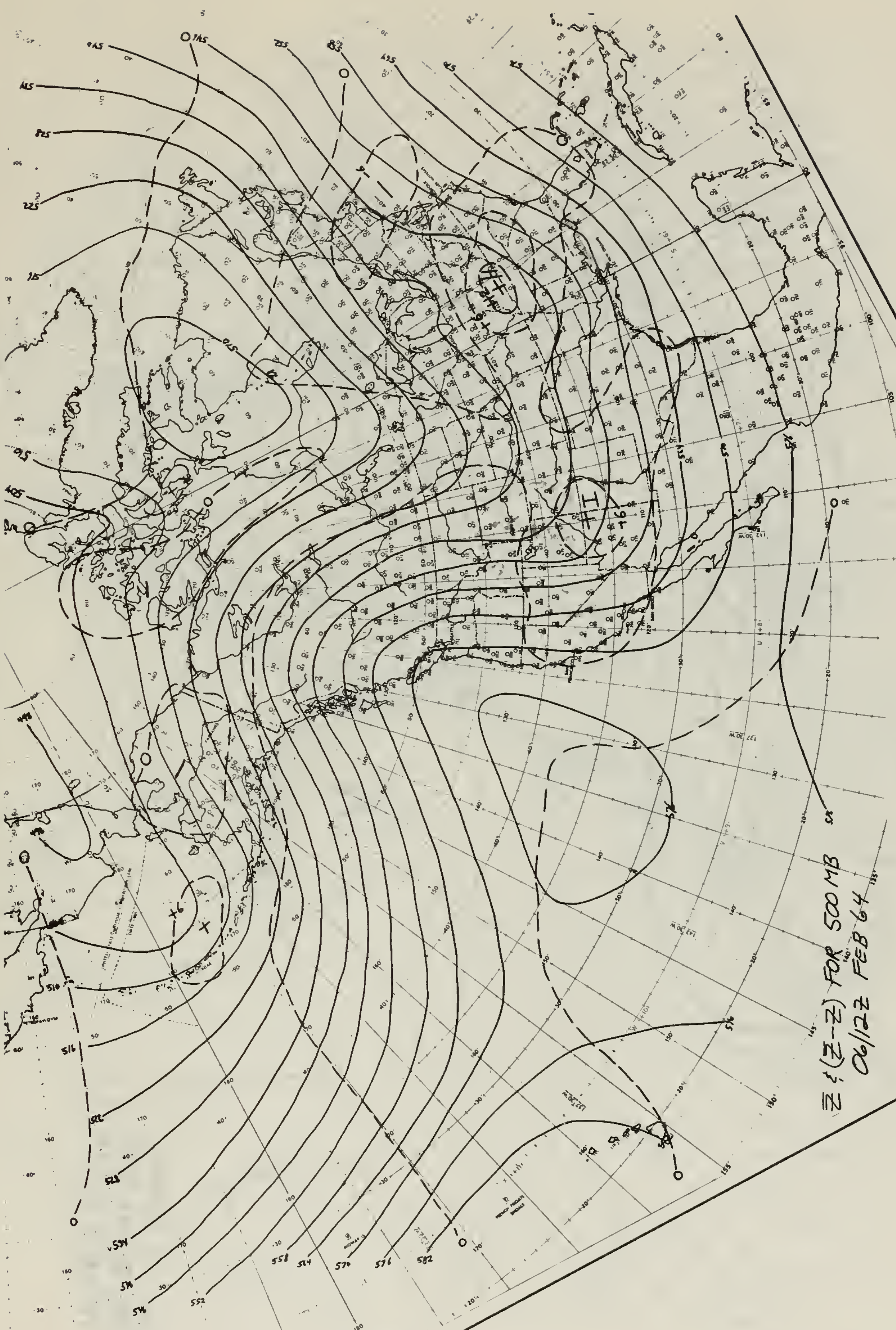


Fig. 30

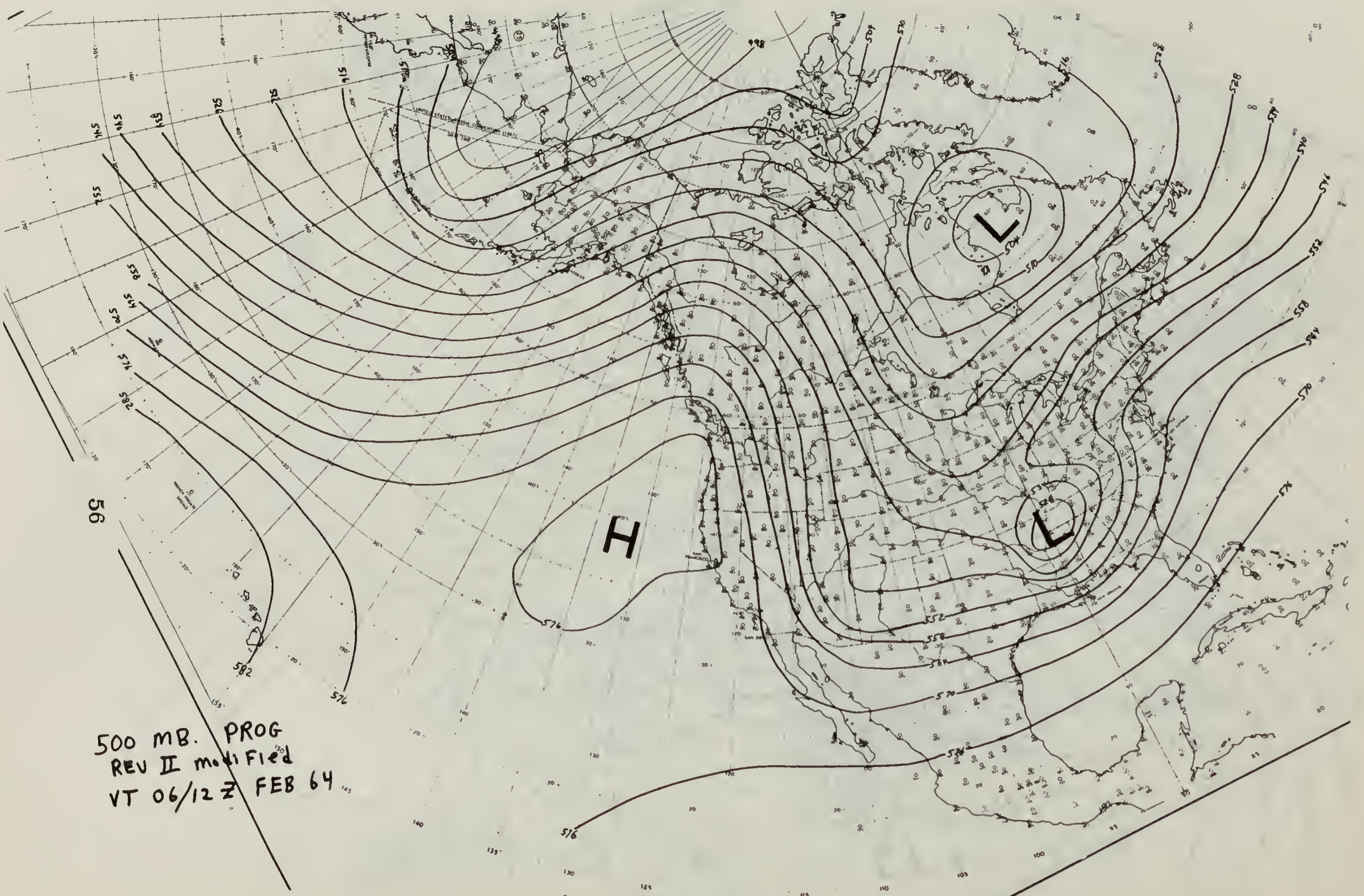


Fig. 31

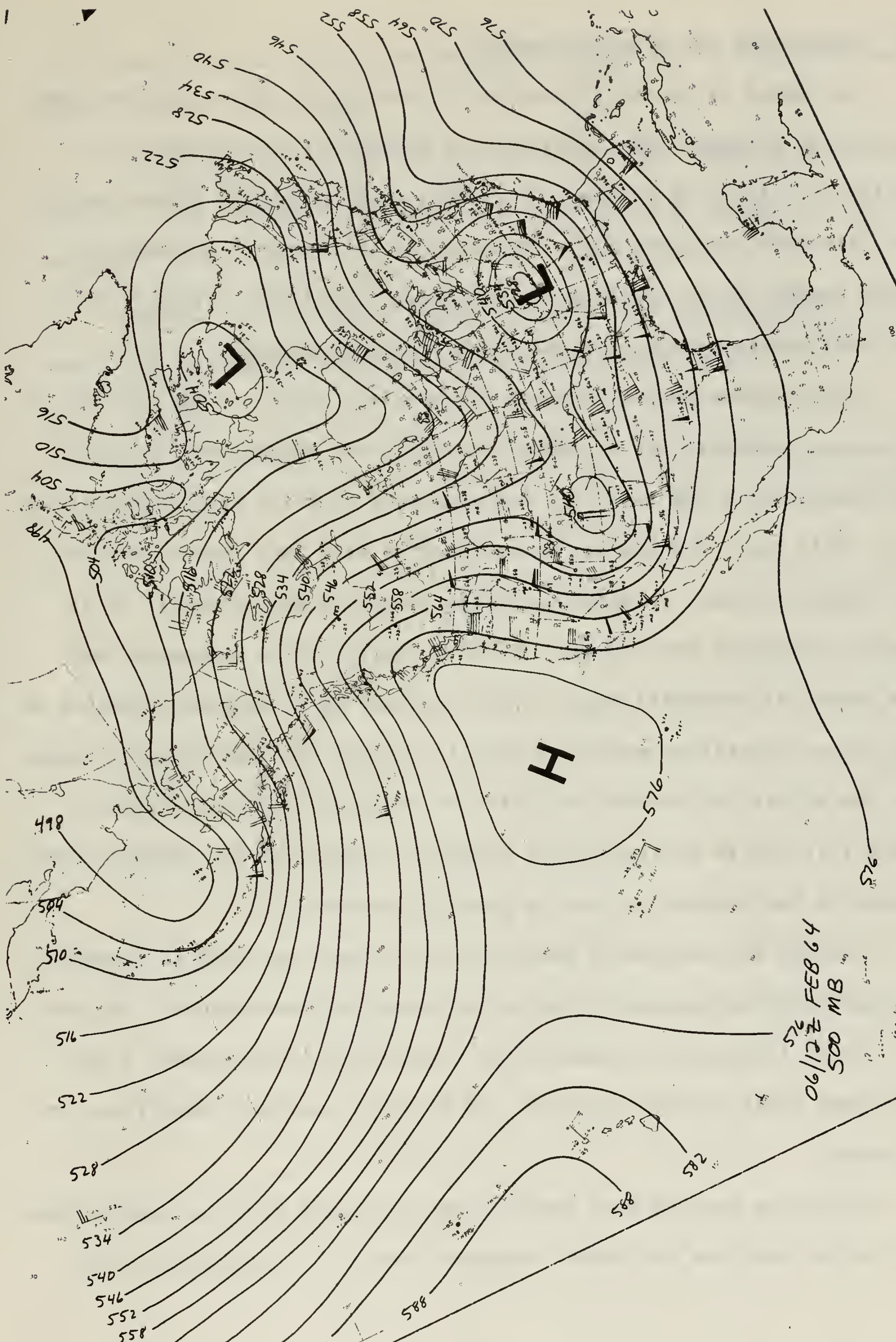


Fig. 32

5. Conclusions and Acknowledgement.

The method of prognosis proposed in this paper for the 500-mb level produced an average .249 improvement in score over persistence in the gradient verification scheme. In general, the prognostic 500-mb charts had quite good correlation for locations of the centers, although the actual height values varied above and below a good bit. Table 2 lists the verification scores attained on the research charts.

This proposed method presents an excellent basis for application of subjective modifications dependent on individual situations, a few of which were seen in the research, and many more of which certainly will be seen. This type of thing can be easily done with this technique since the identity of each relative vorticity center is maintained as it is tracked throughout the process. In this regard, it is suggested that this method of prognosis might find acceptance as a teaching technique as well as an operational method in that it affords one considerable insight into the effect of relative vorticity on isohypses and their centers. Toward this end an outline of the method for practical use together with a table of the correction term is given in Appendix I.

Although not previously mentioned, an attempt was made to produce meaningful 850-mb prognostic charts utilizing the same method. The use of 60-meter intervals was found to be unsatisfactory since only a very few closed $(\overline{Z}-Z)$ centers resulted, and 30-meter intervals were found to be needed.

When these centers were advected and corrected with the same methods and factors used for the 500-mb research rather poor correlation with verifying charts resulted. No further research was conducted to modify the method for this level.

Neither the 700-mb nor the 300-mb levels were investigated. It is possible that favorable results could be obtained at either of these levels.

Professor W. D. Duthie, faculty advisor, has our gratitude for his invaluable advice and assistance in preparing this paper.

TABLE 2

VERIFICATION SCORES OF THE PROGNOSTIC 500-MB CHARTS

These verification scores are determined by a height-gradient verification scheme which is described in Section 4. The score expresses the gradient error between the prognostic and verifying charts, given as a fraction of the total gradient of the verifying chart. Thus, the lower the score, the better is the prognosis as evaluated by this method.

Verifying Date/Time	Prognosis Verification Score		Persistence Verification Score
080000Z JAN 1962	Revision III:	.368	.563
	Fjortoft Method:	.423	
090000Z JAN 1962	Revision III:	.473	.542
	Fjortoft Method:	.526	
100000Z JAN 1962	Revision III:	.376	.463
110000Z JAN 1962	Revision III:	.496	.700
051200Z FEB 1964	Revision II, modified:	.740	.818
061200Z FEB 1964	Revision II, modified:	.262	.812
	Fjortoft Method:	.940	
121200Z FEB 1964	Revision II:	.670	.980
131200Z FEB 1964	Revision II:	.420	1.025
081200Z JAN 1964	Revision II:	.437	.574

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APPENDIX I

PROCEDURE FOR 500-MB 24-HOUR PROGNOSIS

USING A MODIFIED FJORTOFT GRAPHICAL NUMERICAL METHOD

1. Given the current 500-mb chart, analyzed at 60-meter intervals, obtain a space mean-chart, $\overline{Z}$. A grid distance of five degrees of latitude (at 25N) is recommended for the north-south and east-west offsets. Normally only 60-meter intervals need be obtained on the space-mean, but if intermediate space-mean contours are desired they can readily be obtained in the final graphical step of the space-mean process.

2. Obtain $(\overline{Z}-Z)$ by graphically subtracting the current 500-mb chart from the space-mean chart. Recall that this quantity is proportional to relative vorticity. Superimpose the $\overline{Z}$ and $(\overline{Z}-Z)$ fields.

3. Advect the $(\overline{Z}-Z)$ isolines along the space-mean flow for 24 hours. The following recommendations are made to assist in advection: (a) advect each point of intersection of the $\overline{Z}$ and $(\overline{Z}-Z)$ fields, or as many as is practicable; (b) use the space-mean geostrophic wind as measured at the advection point and modify it to approximate the gradient wind. This can be done roughly by multiplying the geostrophic wind by the factor in the following table appropriate to the contour pattern at the initial advection point, interpolating as necessary:

Strong cyclonic curvature as in a trough	½
Very strong cyclonic curvature as for a closed low center	¼
Strong anti-cyclonic curvature as in a ridge	2

Very strong anticyclonic curvature as for a closed high center 4

Inflection points and straight flow 1

Use the resulting wind speed to determine the 24-hour displacement; (c) a subjective modification is recommended where a cut-off low exists. Positive $(\overline{Z}-Z)$ centers in the flow upstream of the low should be advected with the equatorward flow regardless of their location in the flow. Negative $(\overline{Z}-Z)$ centers in the upstream ridge should be advected with the flow poleward of the low, rather than be split or taken equatorward; and (d) if time permits, a more accurate advection is obtained by using two time steps on the same space mean; i.e., advect for <u>12 hours</u> just as before, then measure a new wind value, again applying the gradient approximation, and use this over the final 12 hours. The gradient wind approximation in 3.(b) should be used in each step. This step is especially applicable in troughs, ridges, and where the contours converge/diverge appreciably.

4. Determine and apply the correction term, Table 3, as follows: (a) determine $\overline{v_g}$, the meridional component of the space-mean geostrophic wind, using a geostrophic wind measurement but measuring along latitude circles between contours. Again, this should be done at each intersection point; (b) enter Table 3 with the measured $\overline{v_g}$, $(\overline{Z}-Z)$, and ϕ to obtain the correction term which is then algebraically added to the advected value for a given point. The sign of the correction term, $\frac{\overline{v_g}(\overline{z}-z)}{A(\phi)}$, is determined by the sign of (plus for poleward flow, minus for equatorward flow) and the sign of $(\overline{Z}-Z)$. For example, a negative $(\overline{Z}-Z)$ area being advected equatorward would have a positive correction term, thus decreasing the

magnitude of $(\overline{Z}-Z)$;(c) again, if time allows, a determination of $\overline{v_g}$ and the correction term at the beginning point and again at about the 12-hour point with the mean of the two used will be more meaningful.

5. With modified values of $(\overline{Z}-Z)$ indicated after the correction step, re-draw the $(\overline{Z}-Z)$ lines, adjusting zero lines slightly as necessary (note that zero lines of $(\overline{Z}-Z)$ cannot be corrected by Table 3 since zero values immediately make the term zero). The result of this step, then, is a 24-hour $(\overline{Z}-Z)$ prognosis.
6. Generally, the space mean is assumed to be constant for the 24-hour period so that the 500-mb prognosis results simply from subtracting the $(\overline{Z}-Z)$ prognosis from the original space mean, $\overline{Z}$.

TABLE 3

THE CORRECTION TERM FOR 24-HOUR DISPLACEMENTS

$\overline{v_g}$	5 kts			10 kts			15 kts			20 kts			25 kts		
$(\bar{z}-z)$ meters / ϕ	6	12	18	6	12	18	6	12	18	6	12	18	6	12	18
20	1.2	2.3	3.5	2.3	4.6	6.9	3.5	6.9	10.1	4.6	9.2	13.8	5.8	11.5	17.3
25	.9	1.8	2.7	1.8	3.6	5.4	2.7	5.4	8.1	3.6	7.2	10.1	4.5	9.0	13.5
30	.7	1.4	2.2	1.4	2.9	4.4	2.2	4.4	6.6	2.9	5.8	8.7	3.6	7.3	10.9
35	.6	1.2	1.8	1.2	2.4	3.6	1.8	3.6	5.4	2.4	4.8	7.2	3.0	6.0	9.0
40	.5	1.0	1.5	1.0	2.0	3.0	1.5	3.0	4.5	2.0	4.0	6.0	2.5	5.0	7.5
45	.4	.8	1.3	.8	1.7	2.5	1.3	2.5	3.8	1.7	3.4	5.0	2.1	4.2	6.3
50	.4	.7	1.1	.7	1.4	2.2	1.1	2.2	3.2	1.4	2.8	4.2	1.8	3.5	5.3
55	.3	.6	.9	.6	1.2	1.8	.9	1.8	2.8	1.2	2.4	3.5	1.5	2.9	4.4
60	.2	.5	.7	.5	1.0	1.4	.7	1.4	2.2	1.0	1.9	2.9	1.2	2.4	3.6
65	.2	.4	.6	.4	.8	1.2	.6	1.2	1.8	.8	1.6	2.4	1.0	2.0	2.9
70	.2	.3	.5	.3	.6	.9	.5	.9	1.4	.6	1.2	1.8	.8	1.5	2.3
75	.1	.2	.3	.2	.4	.7	.3	.7	1.0	.4	.9	1.4	.6	1.2	1.7

$\overline{v_g}$	30 kts			35 kts			40 kts			45 kts			50 kts		
$(\bar{z}-z)$ meters / ϕ	6	12	18	6	12	18	6	12	18	6	12	18	6	12	18
20	6.9	13.8	20.1	8.1	16.2	24.2	9.2	18.5	27.8	10.1	20.1	31.2	11.5	23.1	34.6
25	5.4	10.1	16.2	6.3	12.6	18.9	7.2	14.4	21.6	8.1	16.2	24.3	9.0	18.0	27.0
30	4.4	8.7	13.1	5.1	10.0	15.3	5.8	11.6	17.5	6.6	13.1	19.7	7.3	14.5	21.8
35	3.6	7.2	10.1	4.2	8.4	12.6	4.8	9.6	14.4	5.4	10.1	16.2	6.0	12.0	18.0
40	3.0	6.0	9.0	3.5	7.0	10.5	4.0	8.0	12.0	4.5	9.0	13.5	5.0	10.0	15.0
45	2.5	5.0	7.6	3.0	5.9	8.8	3.4	6.7	10.1	3.8	7.6	11.4	4.2	8.4	12.6
50	2.2	4.2	6.4	2.5	4.9	7.4	2.8	5.6	8.5	3.2	6.4	9.5	3.5	7.0	10.6
55	1.8	3.5	5.4	2.1	4.1	6.2	2.4	4.7	7.1	2.8	5.4	7.9	2.9	5.9	8.8
60	1.4	2.9	4.4	1.7	3.4	5.1	1.9	3.9	5.8	2.2	4.4	6.5	2.4	4.8	7.3
65	1.2	2.4	3.5	1.4	2.7	4.1	1.6	3.1	4.7	1.8	3.5	5.3	2.0	4.0	5.9
70	.9	1.8	2.8	1.1	2.1	3.2	1.2	2.4	3.7	1.4	2.8	4.1	1.5	3.1	4.6
75	.7	1.4	2.1	.8	1.6	2.4	.9	1.8	2.7	1.0	2.0	3.0	1.1	2.3	3.4

$\overline{v_g}$	55 kts			60 kts			65 kts			70 kts			75 kts		
$(\bar{z}-z)$ meters / ϕ	6	12	18	6	12	18	6	12	18	6	12	18	6	12	18
20	12.7	25.4	38.1	13.8	27.8	41.5	15.0	30.0	45.0	16.2	32.3	48.5	17.3	34.5	51.5
25	9.9	19.8	29.8	10.1	21.6	32.4	11.7	23.4	35.2	12.6	25.2	37.9	13.5	27.0	40.5
30	8.0	16.0	24.0	8.7	17.5	26.2	9.5	19.0	28.4	10.0	20.4	30.6	10.9	21.8	32.8
35	6.6	13.2	19.8	7.2	14.4	21.6	7.8	15.6	23.4	8.4	16.8	25.2	9.0	18.0	27.0
40	5.5	11.0	16.5	6.0	12.0	18.0	6.5	13.0	19.5	7.0	14.0	21.0	7.5	15.0	22.5
45	4.6	9.3	13.9	5.0	10.1	15.1	5.5	10.9	16.4	5.9	11.8	17.7	6.3	12.6	18.9
50	3.9	7.8	11.6	4.2	8.5	12.7	4.6	9.2	13.8	4.9	9.9	14.8	5.3	10.6	15.9
55	3.2	6.5	9.7	3.5	7.1	10.6	3.8	7.6	11.5	4.1	8.2	12.4	4.4	8.8	13.2
60	2.7	5.3	8.0	2.9	5.8	8.7	3.1	6.3	9.5	3.4	6.8	10.2	3.6	7.3	10.9
65	2.2	4.3	6.5	2.4	4.7	7.1	2.5	5.1	7.7	2.7	5.5	8.2	2.9	5.9	8.8
70	1.7	3.4	5.0	1.8	3.7	5.5	2.0	4.0	6.0	2.1	4.3	6.4	2.3	4.6	6.9
75	1.2	2.5	3.7	1.4	2.7	4.1	1.5	2.9	4.4	1.6	3.2	4.7	1.7	3.4	5.1

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13. ABSTRACT
This paper presents a relatively simple method for producing a 24-hour prognostic 500-mb chart by graphical means. It modifies the Fjortoft graphical method by incorporating a technique to include the intensification and weakening of systems. That is, it uses factors which allow intensification of poleward-moving cyclones and weakening of equatorward-moving cyclones and the converse for anti-cyclones.

The theoretical development of the so-called "geostrophic model" used, the research procedure, and a number of illustrative charts are all discussed and a table of chart verification scores is presented to assist in the reader's evaluation of the method.

It is concluded that this method does provide a simple prognostic procedure which includes some intensity change for systems. The results showed an average 24.9 per cent improvement over persistence for the charts analyzed using a height-gradient verification scheme.

Appendix I outlines the specific procedure for utilizing the method on a practical basis and is included as such for the convenience of potential users.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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